SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

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Aquatic Fungi—Cooke and Bartsch

Refining Wastes—Hodgkinson

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Combined Treatment—Quirk

Operator's Corner

Sludge Density Meter, Sludge Disposal Practices

NOVEMBER 1959—VOL. 31, No. 11

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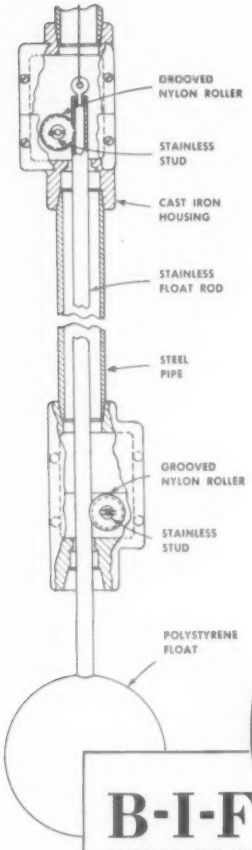

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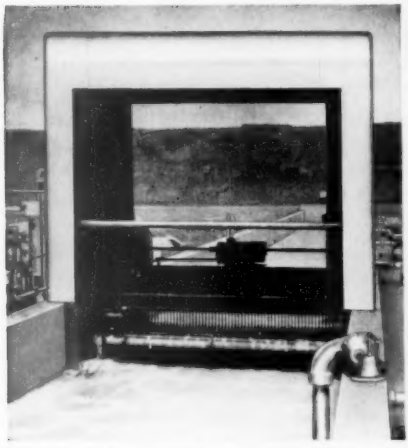

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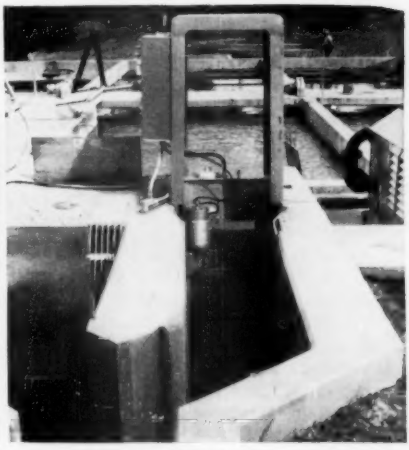

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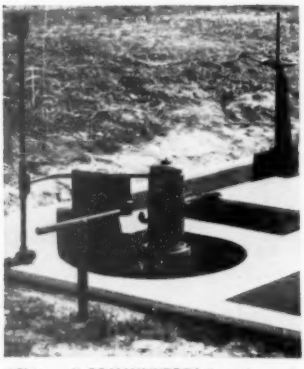

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 31 | November 1959 | Number 11

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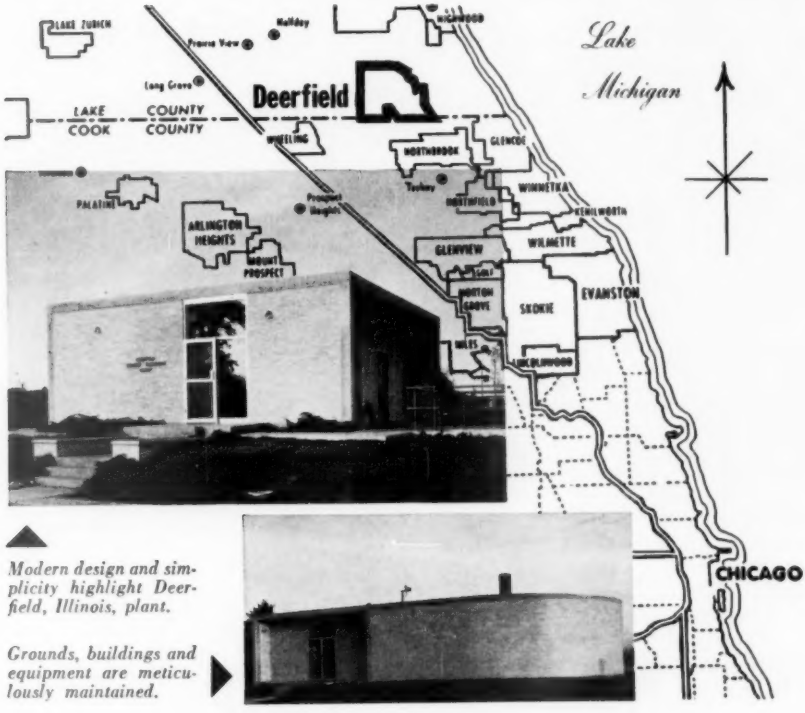

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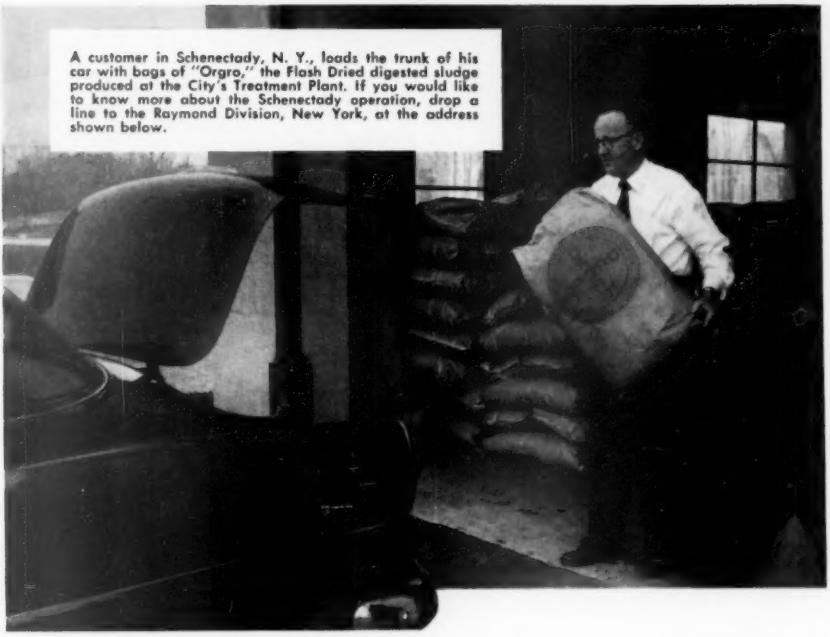

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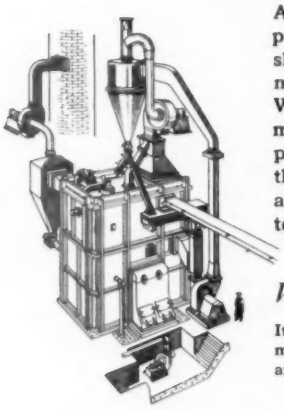

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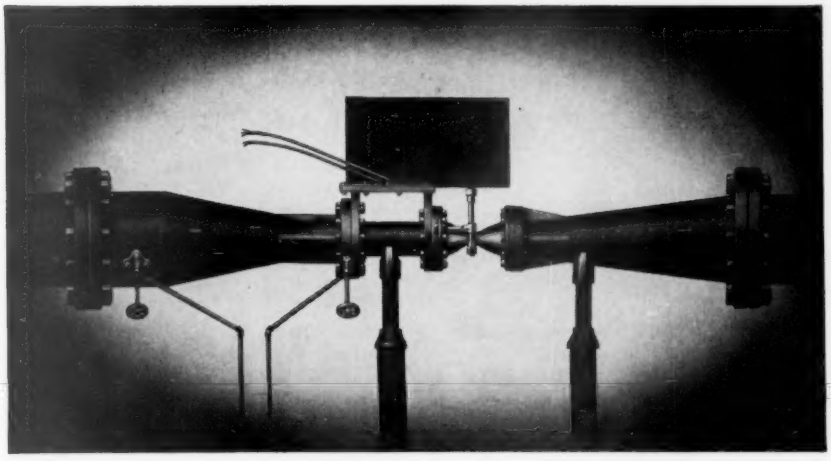

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Association	*Place*	*Time*
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South Carolina Water and Sewage Works Assn.	Jefferson Hotel, Columbia, S. C.	Nov. 6, 1959
North Carolina Sewage and Industrial Waste Assn.	Washington Duke Hotel, Durham, N. C.	Nov. 9–11, 1959
Florida Sewage and Industrial Wastes Assn.	Hillsboro Hotel, Tampa, Fla.	Nov. 15–18, 1959
Oklahoma Water, Sewage and Industrial Wastes Conf.	Student Union, Okla. State Univ. Stillwater, Okla.	Nov. 16–20, 1959
Indiana Sewage and Industrial Wastes Assn.	Washington Hotel, Indianapolis, Ind.	Nov. 18–19, 1959
New York Sewage and Industrial Wastes Assn.	Park Sheraton Hotel New York, N. Y.	Jan. 20–22, 1960

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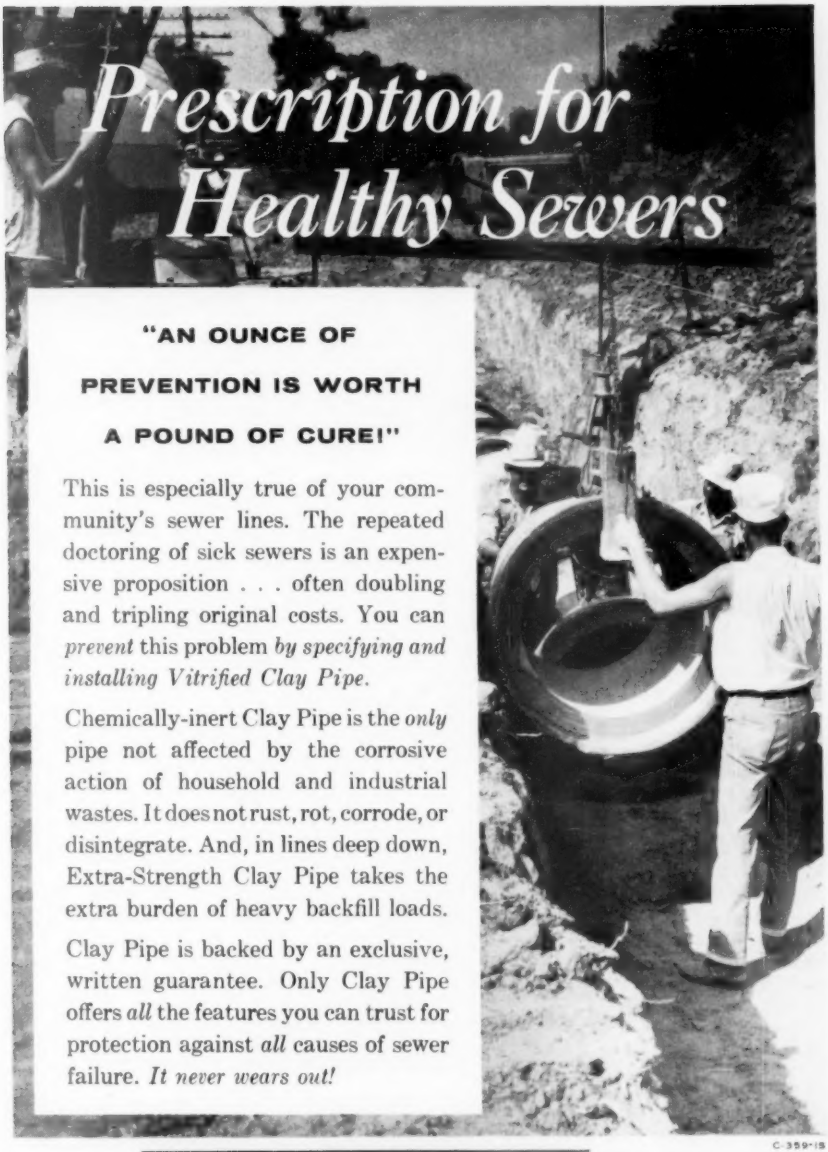
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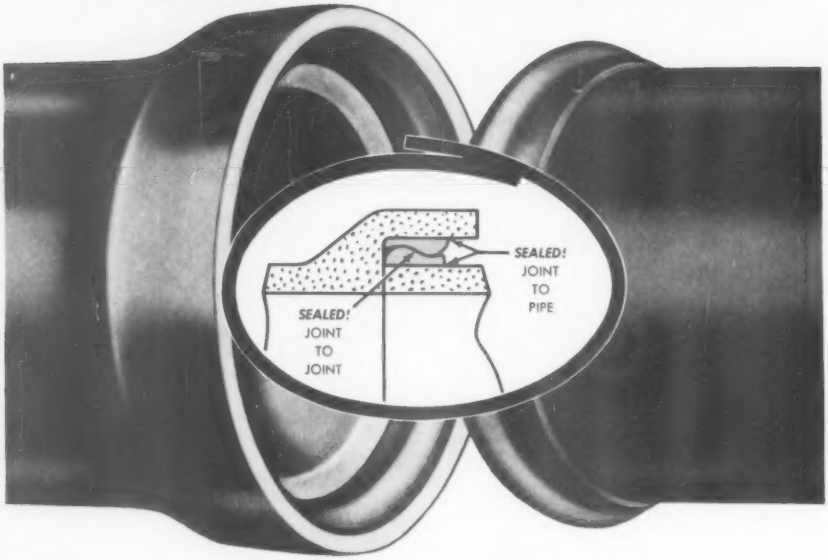

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The Clay City Pipe Company Uhrichsville, Ohio

The Logan Clay Products Company Logan, Ohio

The Evans Pipe Company Uhrichsville, Ohio

The Robinson Clay Product Company Akron, Ohio

Graff-Kittanning Clay Products Worthington, Pa.

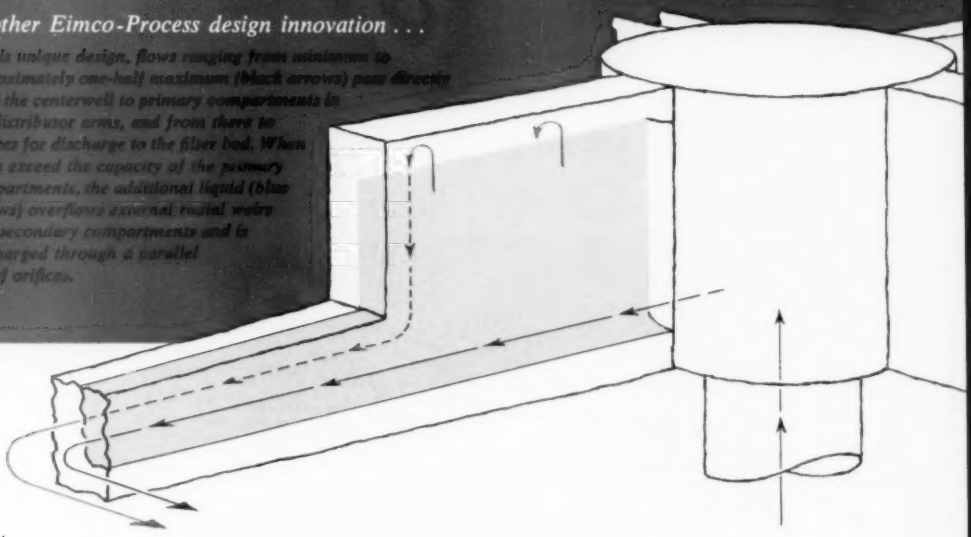
The Stillwater Clay Products Company Cleveland, Ohio

Superior Clay Corporation, Uhrichsville, Ohio

WLC-158-186-B

Another Eimco-Process design innovation . . .

In this unique design, flows ranging from minimum to approximately one-half maximum (black arrows) pass directly from the centerwell to primary compartments in the distributor arms, and from there to orifices for discharge to the filter bed. When flows exceed the capacity of the primary compartments, the additional liquid (blue arrows) overflows external radial weirs into secondary compartments and is discharged through a parallel set of orifices.



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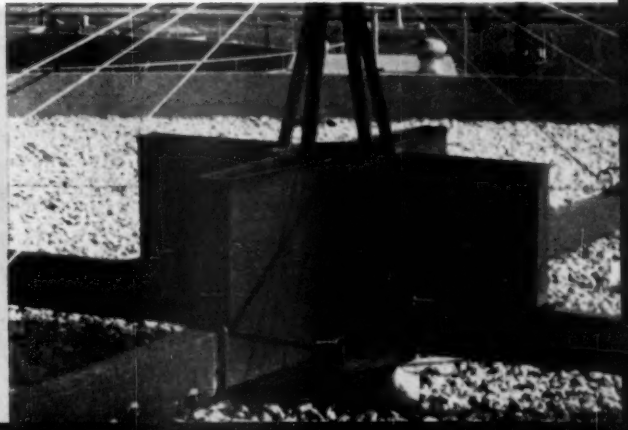

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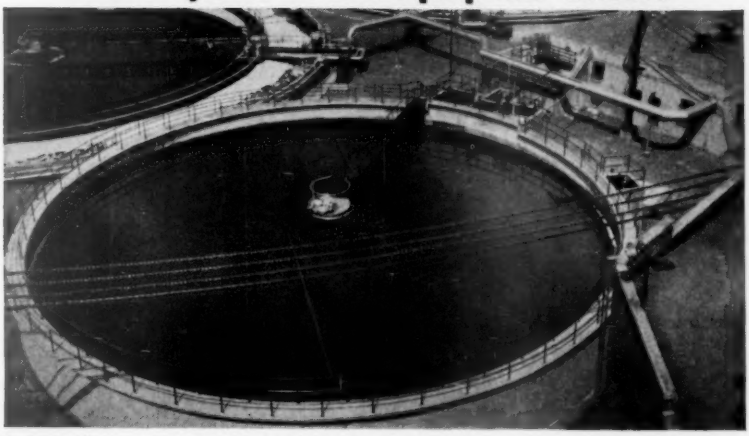
Rodney Hunt gates of tough Everdur withstand bleach-plant acid and pulp-mill wastes



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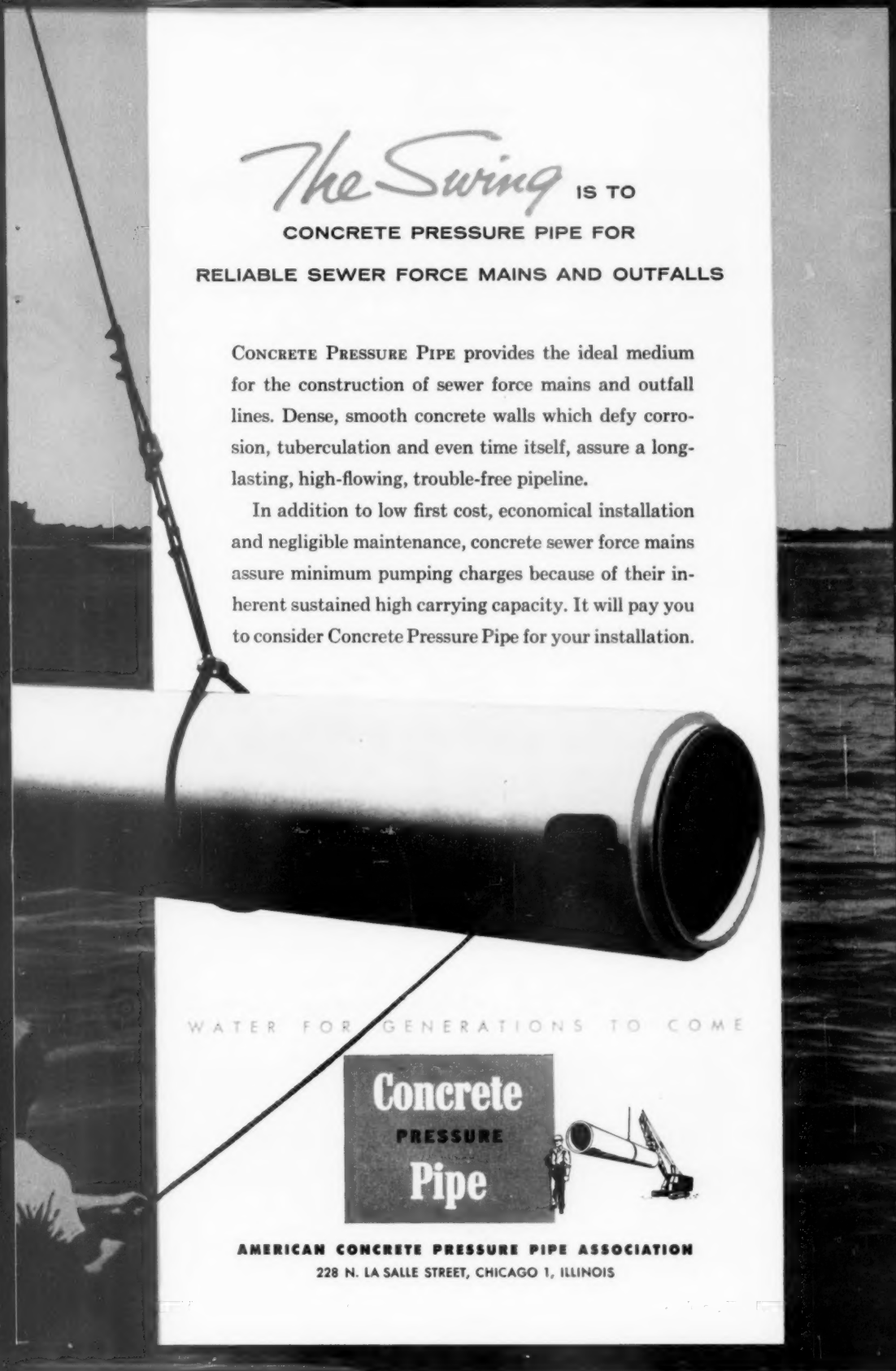

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CONCRETE PRESSURE PIPE provides the ideal medium for the construction of sewer force mains and outfall lines. Dense, smooth concrete walls which defy corrosion, tuberculation and even time itself, assure a long-lasting, high-flowing, trouble-free pipeline.

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Utilize our many years of experience in the development and manufacture of municipal and industrial waste treatment equipment. Our staff of engineers is ready to cooperate with consulting and operating engineers in suggesting the process of treatment and type of equipment best suited to individual needs.

BIO-ACTIVATION—exclusive system combines best qualities of trickling filter and activated sludge. *Bulletin 259B.*

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GREASE FLOTATION UNIT—removes grease and oils, produces simultaneous aeration and agitation, and oxidizes objectionable odors. *Bulletin 260B.*

SEWAGE AND SLUDGE PUMPS—horizontal and vertical pumps in wide range of sizes, capacities and heads—including cutting type primary sludge pumps, enclosed impeller type sewage pumps, single vane impeller type sewage pumps and recirculation pumps. **Send for Bulletins.**

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Revolutionary TRUCK-LODER Frees One Man For Other Sewer-Cleaning Jobs!

To get the full Truck-Loder story, write for the name of your nearest "Flexible" Distributor.

The Truck-Loder Bucket Machine brings the deposits direct from the sewer to truck *non-stop!*

It ends the hard dirty work of manually pulling on the bucket to dump the load; shoveling the deposit from street to truck; and cleaning up the street afterward. It's faster – easier – more sanitary. In other words, it puts an extra man in your Sewer Department at *no extra cost.*

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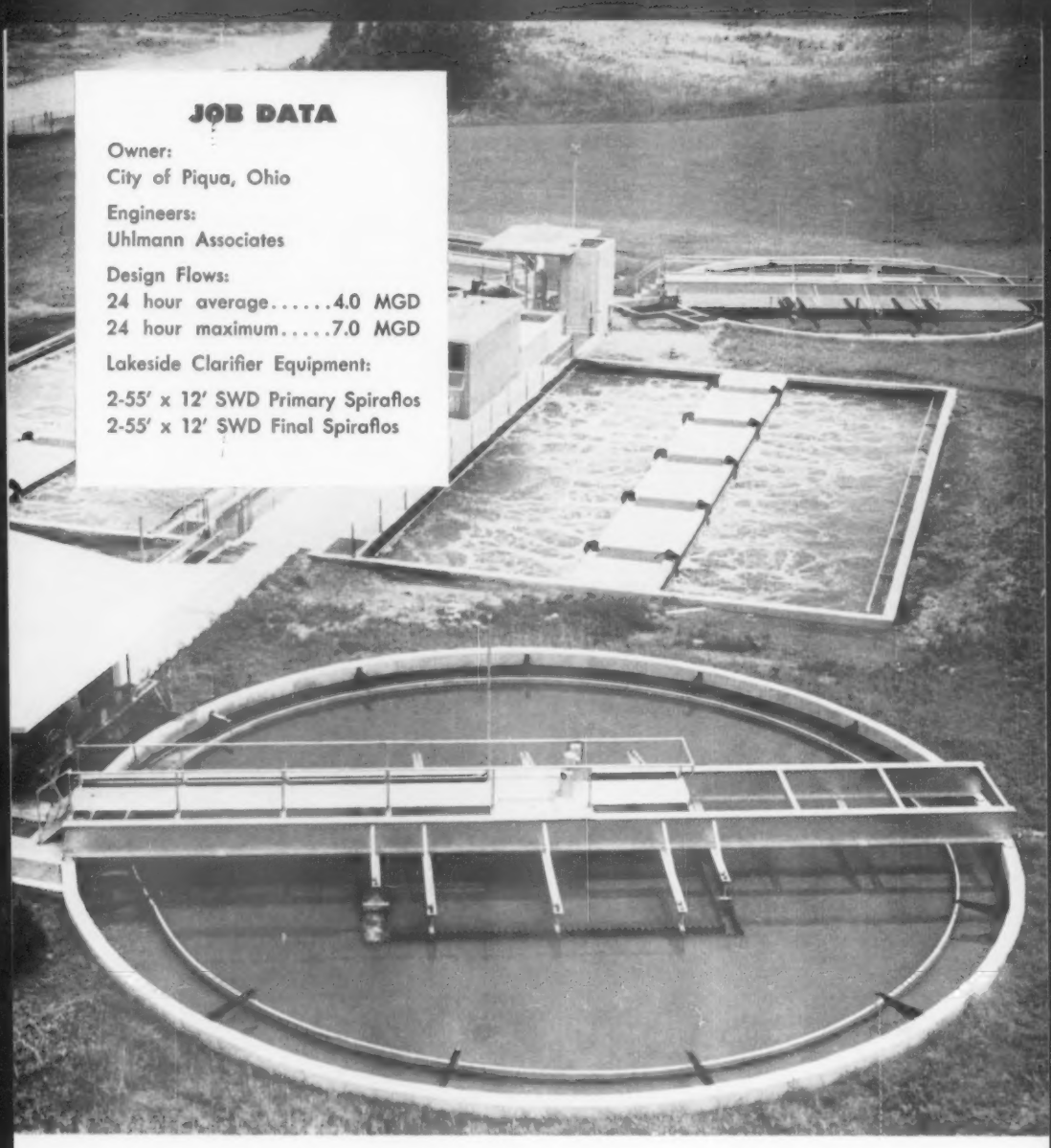

JOB DATA

Owner:
City of Piqua, Ohio

Engineers:
Uhlmann Associates

Design Flows:
24 hour average.....4.0 MGD
24 hour maximum.....7.0 MGD

Lakeside Clarifier Equipment:

2-55′ x 12′ SWD Primary Spiraflos
2-55′ x 12′ SWD Final Spiraflos

SPIRAFLOS—give high removals as both primary and final settling tanks—ideal as finals on activated sludge because of the added depth and the flow pattern that traps the light activated particles in the sludge blanket build up. Also a perfect clarifier for the smaller plants particularly where efficient skimming and scum removal are desired.

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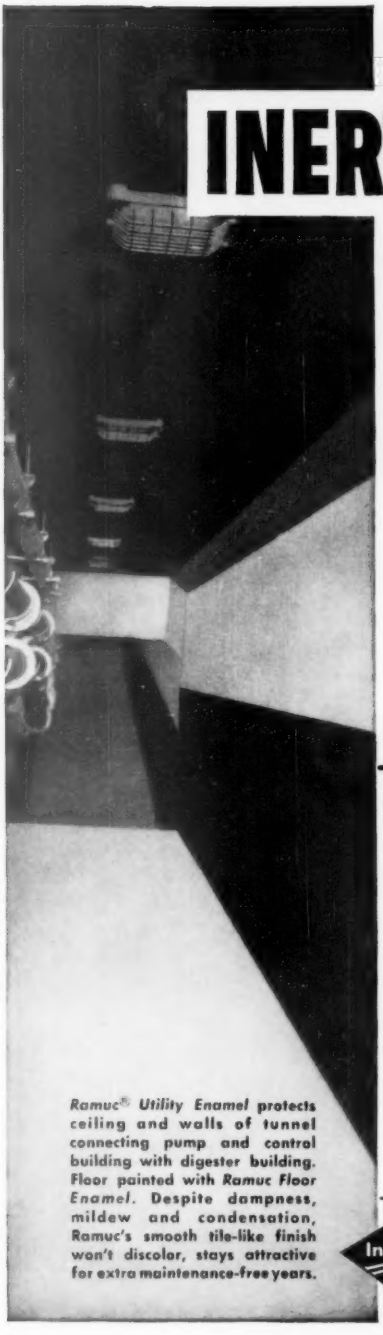

Ramuc® Utility Enamel protects ceiling and walls of tunnel connecting pump and control building with digester building. Floor painted with *Ramuc Floor Enamel*. Despite dampness, mildew and condensation, Ramuc's smooth tile-like finish won't discolor, stays attractive for extra maintenance-free years.

Complete Protection with

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Specified for new 9-MGD Westerly Sewage Plant, Altoona, Pennsylvania

Altoona, Pennsylvania, was one of the first U.S. cities to install and maintain proper sewage facilities. With the new, efficient Westerly plant, designed by Albright & Friel, Inc., Consulting Engineers, Philadelphia, Pa., Altoona continues to show outstanding progress in the sewage works field.

Inertol coatings specified for the Westerly plant assure long-term, low-cost protection... easy-to-clean, attractive surfaces that withstand severe sewage plant conditions. Buy Inertol paints direct from the manufacturer. Shipment within three days from our plant, or from nearby warehouse stocks. For complete information about Inertol coatings, write today for *free* "Painting Guide"—an important tool for Design Engineers, Specification Writers and Plant Superintendents.

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A glossy chlorinated natural rubber-base coating in color for nonsubmerged concrete, steel and indoor wood surfaces.

CONCRETE SURFACES

Colors: Color chart 560.

Number of coats: One coat of *Ramuc Utility Enamel* over two coats of *Ramuc Utility Undercoater*. For a flat finish, apply two coats of *Ramuc Utility Enamel Flat* to bare masonry—omit undercoater.

Coverage: 250 sq. ft. per gal. per coat.

Approximate mil thickness per coat: 1.2.

Drying time: 24 hours.

Primer: *Ramuc Utility Undercoater* (2 coats).

Thinners: *Inertol Thinner 2000-A* for brushing; *2000* for spraying.

Application: Brushing: *Ramuc Utility Enamel*—brush type: as furnished. Spraying: *Ramuc Utility Enamel*—spray type: add sufficient *Thinner 2000* for proper atomization.

(Write for Ramuc specifications for steel surfaces, and for Ramuc Floor Enamel specifications)

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A complete line of quality coatings for sewage, industrial wastes and water plants.

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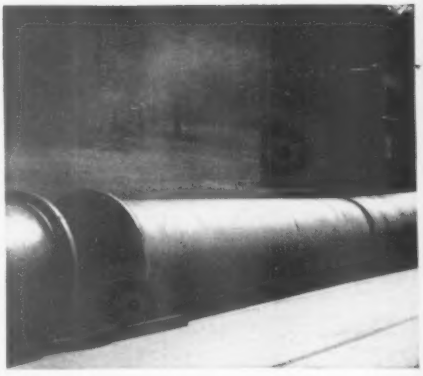
"I PREFER CAST IRON PIPE TO ANY

Recently a questionnaire was mailed to water utility managers all over the U. S. One question asked was: *What kind of pipe do you prefer and why?* With 42 states heard from, the vote is overwhelmingly in favor of cast iron! Here are typical comments from the survey:



"Strength, resistance to corrosion . . . economical first cost, low maintenance and operating cost, good flow characteristics."

—North Carolina

"Our main system is entirely cast iron. It holds up good in 'hot' soil conditions and will not rust out. We are nearing the century mark on some of it, and it gives no trouble."

—Kansas

"Long life—strength—ease of tapping. We are located, as a city, over old mine workings, and subsidence of earth causes trouble on other pipe to a greater extent than on cast iron."

—Illinois

OTHER KIND"

"We have a very hilly city, pressures up to 170 p.s.i. Some of our mains are 90 years old. They were cast iron and are still giving good service."

—Iowa

"Having been used over a long period of time, it has proved its worth. Structurally safe. Easy to repair."

—California

So many good reasons...

- LONG LIFE. The cast iron pipe you install today will perform economically 100 years from now.
- HIGH CAPACITY. Cement-lined cast iron pipe will deliver the full-rated flow all through the years. No other pipe, size for size, can carry more water.
- CORROSION RESISTANCE. Long life proves it. Most water utilities are still using the first cast iron pipe they installed.
- GREAT BEAM STRENGTH. Cast iron pipe resists the effect of heavy traffic, shifting soils.
- TREMENDOUS LOAD RESISTANCE. 6" cast iron pipe (Class 150) withstands a load of nearly 9 tons per foot!
- PRESSURE-TIGHT JOINTS. You have a complete choice of leak-proof, easy-to-assemble joints. You need a minimum of tools and crew.
- EASE OF TAPPING. No tapping saddles needed. Takes threading best of all kinds of pipe.

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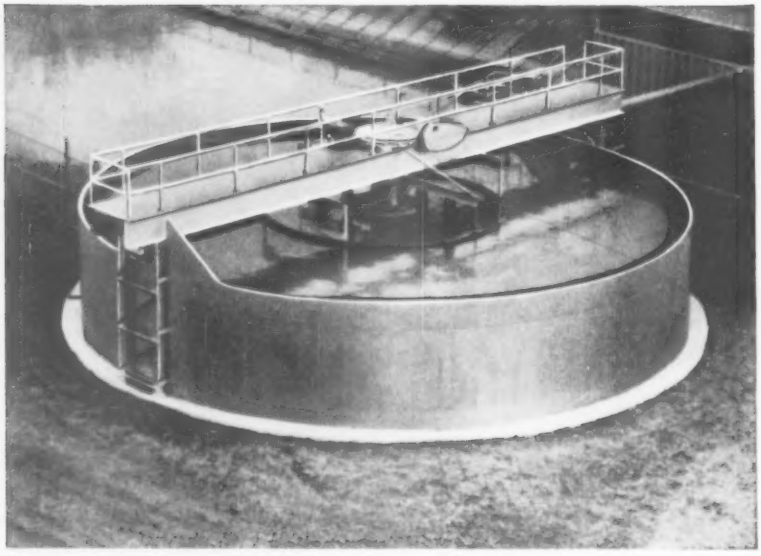

how Scovill Manufacturing Co. found the answer to

TREATMENT OF TUBE MILLS PICKLING WASTES

Dorrco Clariflocculator carries out dual treatment operation in a single tank

Metal pickling wastes from the Scovill Manufacturing Company's brass and copper tube mills at New Milford, Connecticut average 400 gallons per minute of rinse solution.

Removal of zinc and copper carbonates and return of the clarified liquor to the Housatonic River involves a flocculating operation to facilitate rapid settling of the finely divided particles and dissolved salts. The dual operations of flocculation and clarification are carried out in a Dorrco Clariflocculator—a combination unit with two compartments within a single tank.

The Dorrco Clariflocculator is ideally suited to the treatment of wastes involving copper, zinc, aluminum or nickel salts and is adaptable to a wide range of feed volumes and concentrations. Dorr-Oliver engineers have a wealth of experience to bring to the solution of your waste treatment problems. We would welcome the opportunity of talking with you or your consultant. Dorr-Oliver Incorporated, Stamford, Conn.

Consulting Engineers: Metcalf & Eddy, Boston, Mass.

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Sewage Works

USE OF GAS CHROMATOGRAPHY IN SLUDGE DIGESTION

By Jerzy Chmielowski,* James R. Simpson, and Peter C. G. Isaac

Visiting Research Fellow, Senior Research Assistant, and Senior Lecturer in Public Health Engineering (Director of Research); Public Health Engineering Laboratory, Department of Civil Engineering, University of Durham, King's College, Newcastle upon Tyne, England

There is no closely defined rate of loading which differentiates between conventional and high-rate anaerobic digestion. Agitation of the contents of a high-rate unit keeps saprophytic and methane microorganisms well mixed, in contact with the food materials, and in homogeneous conditions of concentration and temperature. The behavior of such a digester and the character of the end products appear to be more closely related to detention time than to organic loading (1).

The problem of detention time of high-rate anaerobic digesters has received some attention in the past. The operation of digesters as high-rate units allows higher loading of organic solids per unit volume with freedom from the usual upsets because of the more efficient use of the space provided. The observations of Rankin (2) indicate that the detention time of the digesting material is the best parameter for evaluating the behavior of the system. Morgan (3) has reported on laboratory and pilot-plant studies with detention times of 7 to 12 days. Torpey (4) presented information on pilot-scale studies which showed that satisfactory digestion could be maintained with detention periods ranging from 11 to 15 days. Sawyer and Roy (5) were able to establish successful digestion using 6 to 20 days holding time under laboratory conditions. Recently Sawyer (6) has discussed the factors affecting high-rate digestion. With this background information at hand, it was considered of interest to carry out some detailed observations of the influence of the detention time on the end products of anaerobic digestion.

The quantity of gas produced by digestion, an important factor in the process, is commonly measured volumetrically. In this work it was found feasible to use simple pressure measurements for the estimation of the gas production rates, and the determination of reaction velocity constants. It appeared useful to employ rotating laboratory sludge digesters, which were found to be simpler in operation than the commonly used gas recirculation or mechanical stirring equipment (5) (7) (8).

Since the composition of fermentation gas has been recognized as a sensitive indicator of the course of anaerobic digestion, an investigation of this composition was considered an essential part of the study. Grune *et al.* (9) tried to use gas chromatography for analysis of sludge gas on a routine basis. Here, it was decided to use

* Present address: Laboratory of Water and Sewage Technology, Silesian Technical University, Gliwice, Poland.

argon for chromatographic elution and a beta-radiation ionization chamber to detect the various components of the fermentation gas as being particularly convenient for the purpose of the investigations. Such a device (10) (11) was adopted and built during the course of the studies (12).

These investigations were undertaken in an effort to observe simultaneously and under controlled conditions the effect on digester performance of detention times of 6.7 to 20 days.

Experimental Methods and Materials

Laboratory Digesters

Sludge digestion was carried out in rotating laboratory digesters, which are shown in Figures 1 and 2. These digesters consisted of 10-liter hard-glass bottles supported on rubber-covered rollers, with their axes horizontal. They were fitted inside with two clear plastic paddles and the assembly was continuously rotated at about 7 rpm. A length of rubber and plastic tubing which could be sealed with a screw clamp provided access to the bottle for the feeding and extraction of sludge. These operations were effected using a 250-ml metal wound syringe. A rubber serum cap, acting as a valve, allowed gas-exchange, pressure measurements, and withdrawal of gas samples using hypodermic needles as the connections to the other equipment employed. The ingress of air during feeding and sampling was effectively prevented by carrying out these operations with the feed tube under the surface of the liquid and with the pressure in the container above that of the atmosphere. Anaerobic conditions were thus maintained. Rotation of the digester provided thorough mixing of the reacting materials and prevented

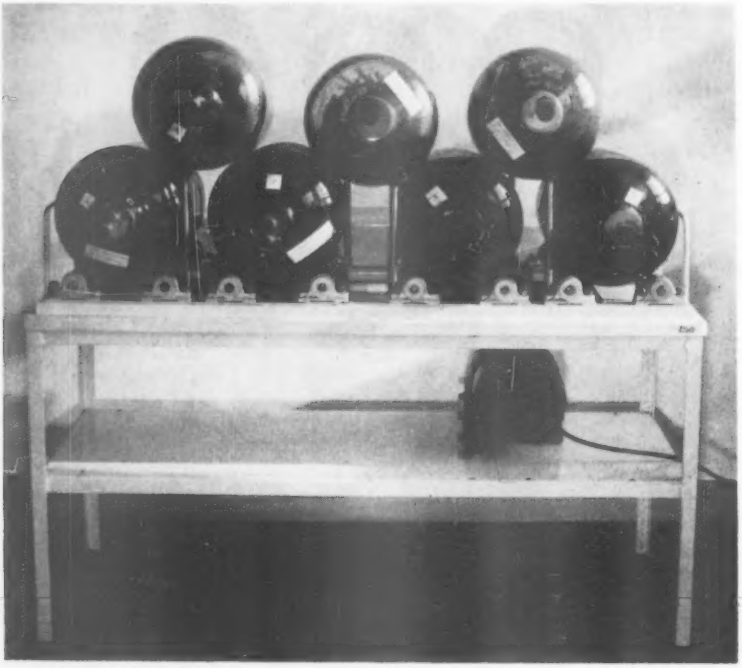

FIGURE 1.—Laboratory digestion equipment showing means of rotating individual digesters.

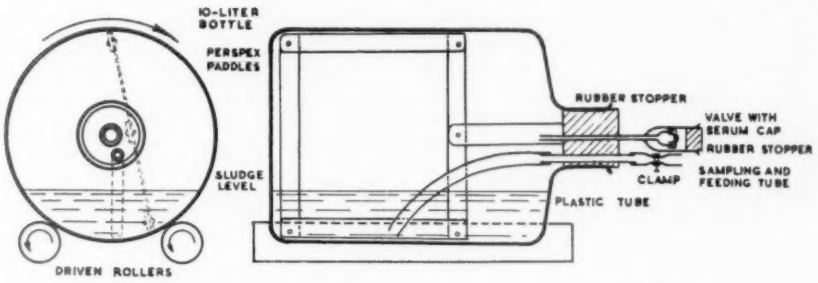

FIGURE 2.—Schematic diagram of rotating laboratory digester.

the formation of scum and sludge layers. The contents of the digesters were so mixed that a continuously changing film of digesting sludge in intimate contact with the gas phase was produced on the interior walls of the digesters.

The digesters were installed in a room in which the temperature was maintained at 32 to 33°C with the aid of a thermostatically controlled heater and fan. This temperature of operation was chosen to lie within the optimum range for mesophilic digestion.

Sludge

The raw sludge used in these studies was obtained from a sewage treatment plant receiving almost wholly domestic wastes. Approximately 10 gal of mixed raw primary and secondary sludge were comminuted by passing through a 3/16-in. sieve to facilitate feeding. The raw sludge when received in the laboratory showed signs of septicity as indicated by a pH of less than 6. The sludge was stored in small containers in a cold room at − 17 to − 13°C. When necessary, a container was withdrawn and the sludge was melted at room temperature. During thawing its temperature was not allowed to rise much above the freezing point. The sludge was then stored at about + 4°C in laboratory refrigerators. The character of the sludge being fed to the digesters was thus controlled during the course of the experiment.

The actively digesting sludge used as seeding material for the laboratory digesters was taken from a mesophilic sludge digester at another sewage treatment plant working at a temperature of 28 to 29°C, and was employed immediately after a short transport time.

Operating Cycle

Five digestion units were charged with 2 or 3 liters of actively digesting sludge and were evacuated by vacuum pump to about − 710 mm Hg (gage). This negative pressure was eliminated after about 4 days of operation by the generation of fermentation gas. When a small pressure above atmospheric was reached, three of the digesters were fed once daily with 150, 200, and 300 ml of raw sludge to give theoretical detention times of 20, 10, and 6.7 days.

For purposes of later identification the digesters are identified in Table I.

An amount of mixed liquor, equal to the volume to be fed, was withdrawn

TABLE I.—Identification of Digesters

Digester	Daily Feed (ml)	Detention Period (days)	Active Digester Volume* (liters)
A	150	20	3
B	200	10	2
C	300	6.7	2

* Volume of digesting sludge in the 10-liter digester.

by the wound syringe from each digester just prior to the feeding. This feeding was started on five per cent daily exchange and gradually increased until all units were operating at the desired detention periods, when routine analyses and other observations were started.

Two further digesters (D and E) containing three liters of the digesting sludge used for seeding all the digestion units, were not fed daily and were taken as blank controls. They operated in "batch" conditions with the removal of 150-ml samples every 5 to 7 days for analytical control of the course of batch digestion.

The duration of these experiments was approximately 32 days. After that, feeding of Digesters A, B, and C was stopped, and digestion was allowed to continue, under "batch" conditions similar to those in Digesters D and E, for the next 14 days. During this time observations were made to ascertain how the batch digestion was affected by the previous feeding conditions.

All digesters were operated simultaneously to minimize the effect of accidental changes in experimental conditions.

Analyses

The homogenous samples of digested sludge removed from the digesters had a volume of 150 to 300 ml. They were analyzed several times per week for volatile acids, alkalinity, total and volatile solids, and pH. The raw feed sludge was analyzed twice weekly. All these analyses were conducted in accordance with "Standard Methods" (13).

Filterability Tests

The ease with which water could be removed from the raw and digested sludges was occasionally determined. For these filterability tests, 100 ml of sludge was poured onto a Whatman No. 1 filter paper on a Buchner funnel. A vacuum of 12 in. of mercury was gradually applied by 4 uniform increments over 2 min. At that time measurements of the filtrate volume were recorded at various time intervals up to 20 min, and the relationship between volume of filtrate and time was expressed graphically.

Microbiology

No attempt was made to isolate and identify the active microorganisms. Occasional microscopic examinations were made on sludge or supernatant liquor to observe the morphology of the microorganisms involved.

Gas Production Measurements

Gas production rates, cumulative, and ultimate gas productions were calculated from pressure measurements. Each day, before any sludge withdrawal or exchange, the gas pressure in each digester was measured using a mercury manometer. This was equipped with a hypodermic needle to penetrate the rubber cap. The temperature of digestion and the atmospheric pressure were also recorded. After these measurements the excess gas was let out and the pressure in the digester was adjusted to atmospheric by piercing the rubber cap with a hypodermic needle. In view of this procedure it was convenient to leave some residual excess pressure during sludge-sample exchange to prevent the entry of air to the digester when pressures were equalized.

There was some danger of operating with glass containers under internal gas pressure; however, this danger was limited by carrying out the experiments with active sludge volumes such that the gas evolved during digestion did not produce a pressure above about 350 mm Hg.

Knowing the total volume of the digester, the volume of digesting sludge, the temperature, and the pressure in the digester it was possible to calculate the volume of gas produced

by the fermentation. Under the conditions of these experiments it was possible to apply the laws of a perfect gas for this calculation without any significant errors. The solubility of the gases in the liquid phase was also neglected. This procedure eliminated the necessity for separate gas collection equipment and for volumetric gas measurements under atmospheric pressure with the accompanying inconvenience; it would have been particularly difficult because of the rotation of the digesters.

It was necessary to correct the gas measurements for water-vapor pressure, temperature, and variations in atmospheric pressure. To reduce a reading to standard condition of dry gas at 760 mm Hg pressure and 0°C temperature, the usual formula may be employed, *i.e.*,

$$V_N = V \frac{b_{dg} T_N}{b_N T} \quad \ldots\ldots (1)$$

and

$$b_{dg} = b_m + b - b_s \quad \ldots\ldots (2)$$

where

V_N = volume of dry gas at standard temperature and pressure,
V = volume of gas above sludge in digester,
T_N = absolute temperature at standard temperature and pressure,
T = absolute temperature of the measured gas,
b_N = absolute pressure at standard temperature and pressure, in mm Hg,
b_{dg} = absolute pressure of dry gas in digester,
b_m = pressure of gas in digester read from mercury manometer,
b = atmospheric pressure in mm Hg, and
b_s = water vapor pressure at the temperature of digester.

Since the digester volume V and temperature of digester T were constant, the equation becomes

$$V_N = b_{dg} \cdot \text{constant} \quad \ldots\ldots (3)$$

In calculating the value of b_{dg} for substitution in this formula, corrections to the barometric and manometric readings were neglected. Errors due to the changes of atmospheric pressure were insignificant during the series of observations and were, therefore, neglected. Before adjusting the pressure of the gas to atmospheric, the volume of the gas was equal to Cb_{dg}, where C was a constant. After the removal of gas to restore atmospheric pressure, the volume of gas is equal to $C(b - b_s)$. Therefore the volume of gas produced and removed (V_{prod}) is given by

$$V_{\text{prod}} = Cb_{dg} - C(b - b_s) \quad \ldots (4)$$

$$V_{\text{prod}} = Cb_m \quad \ldots\ldots\ldots\ldots\ldots (5)$$

All daily gas production rates and cumulative gas productions were calculated from this formula and are expressed as milliliters of gas per day per liter of active digester volume.

Reaction Velocity Constant

An attempt was made to apply the first order equation to the experimental gas production observations. Fair and Moore (14) proposed an approximate mathematical formulation of the course of digestion. The application of the first order equation, which is found satisfactory, is based on the assumption that the velocity of the decomposition of the organic matter, as a whole, is a function of the concentration of that remaining to be decomposed.

The differential equation defining the decomposition as a monomolecular reaction is

$$\frac{dy}{dt} = k(G - y) \quad \ldots\ldots (6)$$

where

G = total amount of gas generated during digestion,
y = amount of gas produced in time t,
t = time in days, and
k = reaction velocity constant.

This gives

$$y = G(1 - e^{-kt}) \ldots\ldots (7)$$

The method used by Schulze (7) to determine k from the experimental results was found to be the simplest and quite adequate for the purpose of these studies. The cumulative gas production during batch digestion is plotted. If k is made equal to $1/t_1$ Equation 7 becomes

$$y_1 = G(1 - e^{-1}) = 0.63\,G \ldots (8)$$

where y_1 is the value of y at time t_1. Using that value in the equation, k can be calculated as the reciprocal of the time in which 63 per cent of the cumulative gas production was achieved. For instance if this amount (y_1) is equal to 3,351 ml ($G = 5{,}352$) and found from the graph to correspond with $t_1 = 3.3$ days, $k = 1/3.3$, which is equal to 0.3.

It is interesting to compare the gas production rates observed during the batch digestion period with those predicted by Equation 6. It is convenient to use an alternative differential form of the monomolecular equation:

$$\frac{dy}{dt} = kGe^{-kt} \ldots\ldots\ldots (9)$$

As an approximation:

$$\frac{\Delta y}{\Delta t} = kGe^{-kt}$$

For a time increment $\Delta t = 1$ day, the daily gas production rate $\Delta y = z$ at time t is given by

$$z = kGe^{-kt}$$

The values of cumulative gas production and daily gas production rates, calculated from the experimental results, were plotted against time in days and both were compared with the theoretical curves as shown in Figure 3.

Gas Analysis

Gas chromatography was used for the analysis of the fermentation gas.

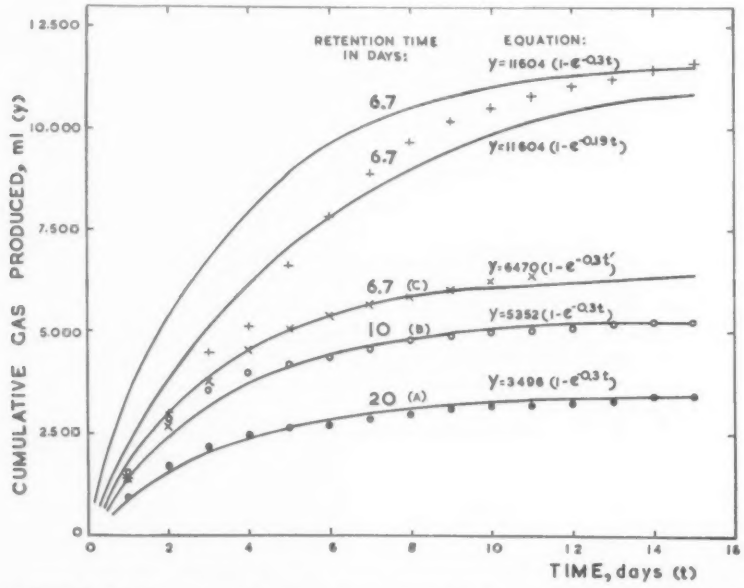

FIGURE 3.—Comparison between experimental and theoretical cumulative gas production during batch digestion.

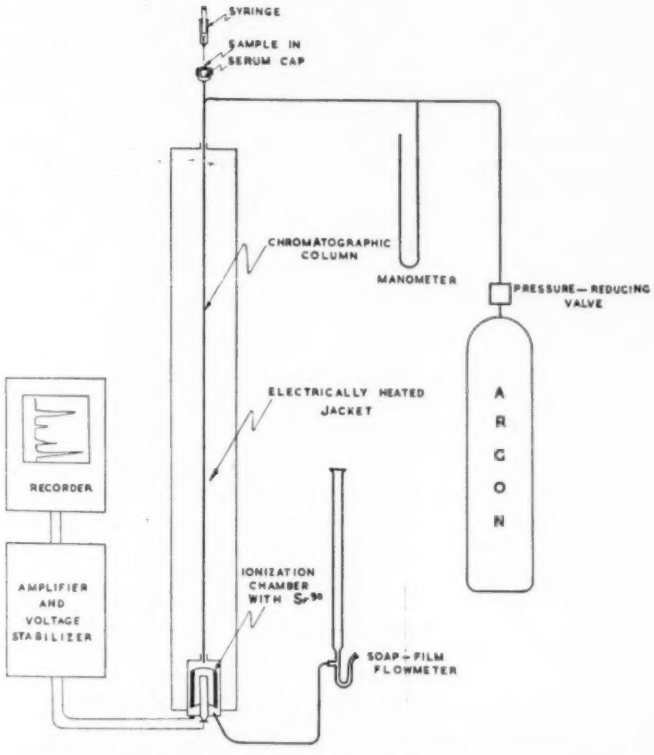

FIGURE 4.—Schematic diagram of apparatus for gas chromatography.

The various components of this gas were separated by argon elution from an adsorption column, packed with activated carbon. The detection of these components was achieved by a beta radiation ionization chamber (10) (11). A method based on this principle allowed the determination of hydrogen, nitrogen, methane, and carbon dioxide during a single analytical procedure (12).

The gas chromatography apparatus as shown in Figures 4 and 5, consisted of the sample injection system, chromatographic column in an electrically heated jacket, beta radiation detector, soap-film flowmeter, manometer, and carrier argon supply cylinder with reducing valve.

The chromatographic column used was a glass tube approximately 4 mm in diameter and 4 ft long packed with about 6.5 g of activated carbon ground to 30 to 70 mesh. An electric heating jacket, equipped with contact thermometer for temperature control, surrounded both the chromatographic column and the ionization chamber. A constant temperature of 50°C ± 0.5° was chosen to insure the stability of the chromatographic sorption processes. The flow rate of carrier argon was fixed at 46 ml/min, which required an input pressure of 230 mm Hg. Samples of 10 ml of fermentation gas were measured under atmospheric pressure by hypodermic syringe and were introduced to the flow of carrier argon through a rubber serum cap on the top of the charcoal column.

The cylindrical ionization detector was constructed of brass. A spark plug, modified by the addition of a brass cap was used as the central collecting electrode. It was isolated from the body of the detector and was surrounded by a silver-foil cylinder holding the radioactive material, 10 mc of strontium-90. This was mechanically and electrically joined to the body of the chamber. The gas in the detector was bombarded with beta particles and was ionized. A potential of approximately 300 v between the radioactive electrode and the walls of the chamber was provided from a voltage stabilizer. Under these conditions ionization currents were collected by the central electrode, amplified, and recorded by a potentiometric recorder. The amplifier was adjusted so that the recorder indicated the chosen zero for constant flow of pure argon through the ionization chamber and gave deflections for argon carrying other gases. The gaseous constituents were recorded as separate peaks on the time-deflection graph of the recorder. Relationships between peak height and volume of gas sample for hydrogen, nitrogen, methane, and carbon dioxide were established under selected constant conditions. These calibration curves, shown in Figure 6, were used for the analytical determination of the gases produced by anaerobic digestion. Higher sensitivity of the ionization detector for hydrogen and nitrogen than for carbon compounds was observed so that the errors of gas determination were dependent on the nature of gas analyzed. These errors were, however, no more than a few per cent.

The measurement of carbon dioxide was to a large degree influenced by the process of sorption onto the activated carbon of the column. The calibration curve for carbon dioxide had the characteristics of an adsorption isotherm. This was not convenient for quantitative determinations of carbon dioxide concentrations greater than about 40

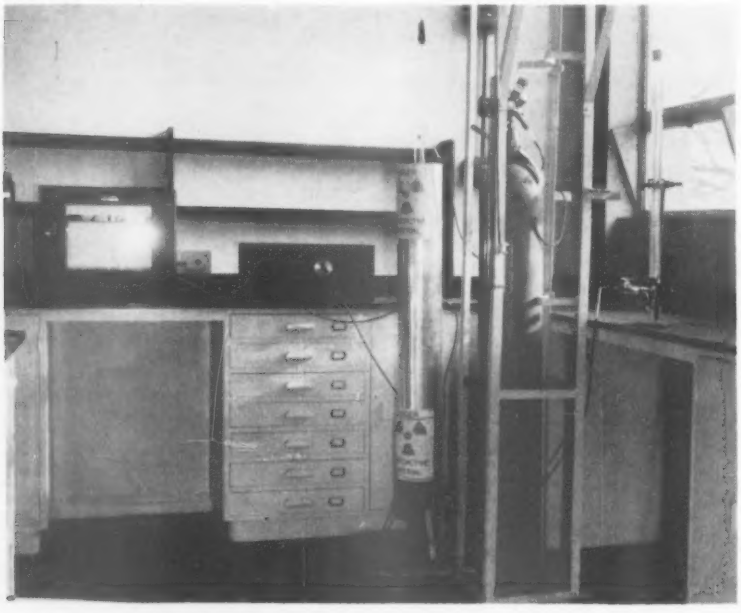

FIGURE 5.—Gas chromatographic equipment.

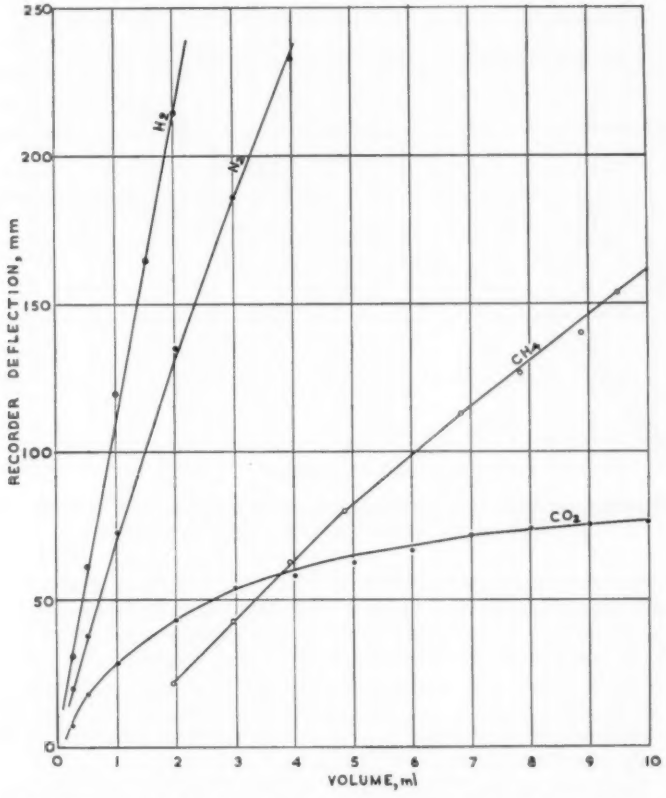

FIGURE 6.—Relationship between instrument peak deflection and volume of gases analyzed by gas chromatography.

per cent; such values did not occur in these investigations. For greater concentrations of carbon dioxide it is more satisfactory to measure the area under the peak rather than the peak height. Such a peak-area calibration curve for carbon dioxide is shown in Figure 7. Gas samples from each digester were analyzed every day to follow the changes in gas composition during anaerobic digestion.

Results

Destruction of Organic Matter

The raw sludge feed and digested sludges withdrawn from the digestion units were analyzed for total and volatile solids, volatile acids, alkalinity, and pH. The results obtained from analyses of numerous samples have been averaged. These results are shown in Table II.

The high concentration of volatile acids in the raw sludge and its low pH show that the first stage of fermentation had begun and that some part of the putrescible matter had been broken down into volatile acids before the sludge reached the laboratory.

There were no substantial differences in composition of sludges from digesters with different detention times. It can be seen, however, that total solids and concentration of volatile

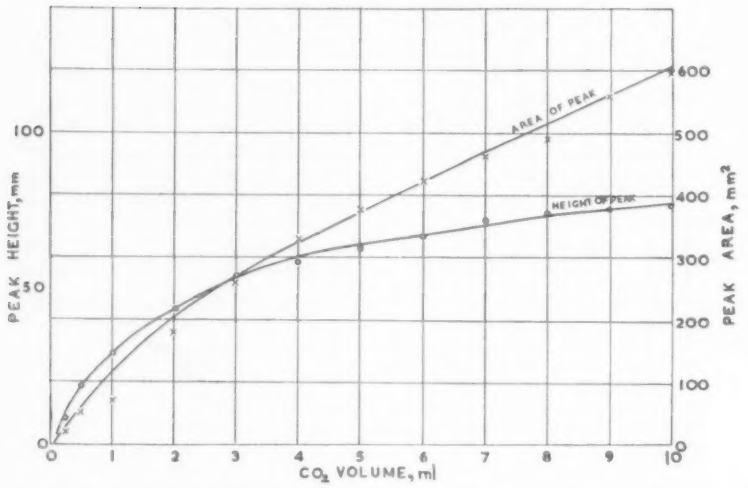

FIGURE 7.—Relationship of instrument peak deflection, and area under peak, to volume of CO_2 in gas chromatographic determination.

acids decreased with increasing detention time. Digested material contained more than 54 per cent of volatile solids and had pH values of about 6.8 to 6.9.

The analyses which were performed during these investigations are summarized graphically in Figures 8, 9, and 10, representing Digesters A, B, and C. These curves show that there was no appreciable difference between the behavior of Digesters A and B. The double rate of feed of Digester B, as compared with A, corresponds to an approximately double rate of gas production. Approximately the same proportion of the organic matter is decomposed in each of these two digesters. It cannot be concluded, with certainty, from Figures 8, 9, and 10 that the digesters had reached steady conditions, although it does appear that Digesters A and B were relatively stable. Digester C was rather unstable; the gas production in this digester was impeded by overloading.

For all units the pH values varied within the usual range. It is perhaps worthy of notice that Digester B produced slightly higher alkalinity than the other two.

Gas Production

The observation of a few units operated simultaneously provided an opportunity to gain information on gas

TABLE II.—Composition of Raw and Digested Sludge

Determination	Raw Sludge	Digested Sludge		
		Digester A	Digester B	Digester C
Total solids (per cent)	3.14	2.89	3.50	3.54
Volatile solids (per cent)	64.8	54.7	54.1	54.6
Volatile acids (mg/l)	2,050	915	1,004	1,207
Alkalinity (mg/l)	1,056	2,111	2,381	2,014
pH	5.1–5.5	6.8–6.9	6.8–6.9	6.8–6.9

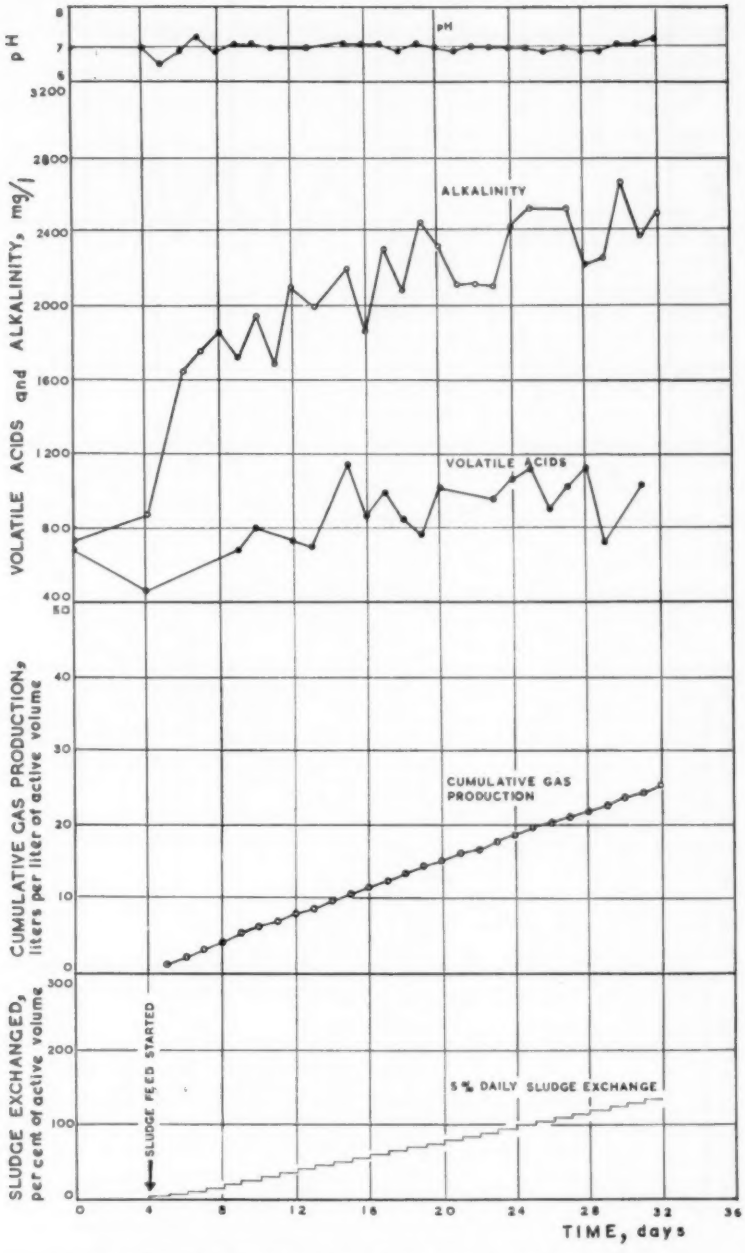

FIGURE 8.—Performance data for Digester A (20-day detention).

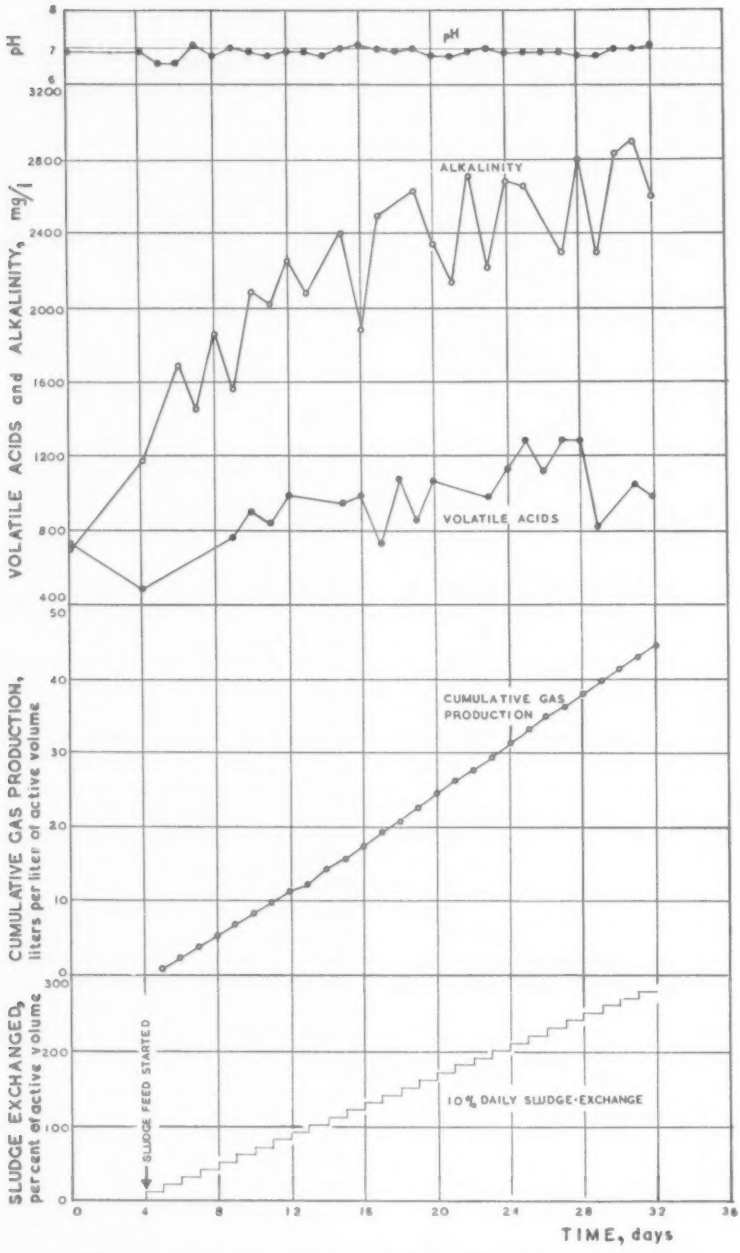

FIGURE 9.—Performance data from Digester B (10-day detention).

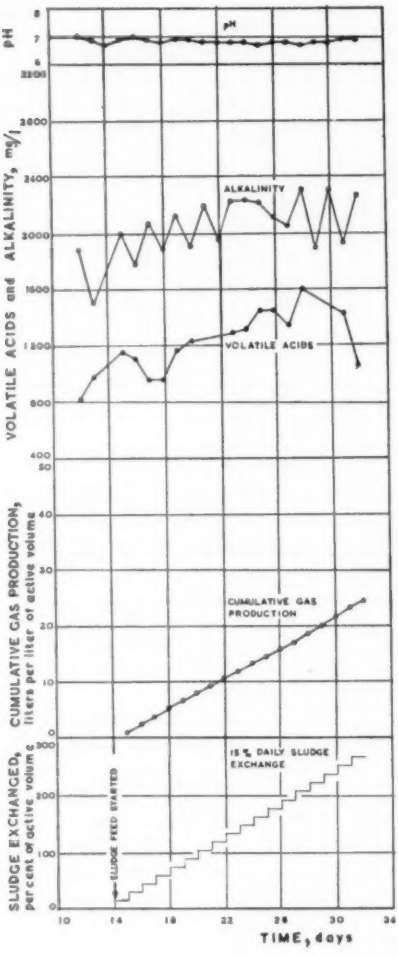

FIGURE 10.—Performance data from Digester C (6.7-day detention).

yield in relation to the detention periods in the digesters. Daily rates of gas production during the feeding cycle are shown in Figure 11. These rates of gas production are compared with gas generation during batch digestion of the seed sludge, set up as a control.

After it was estimated that the initial seed sludge had been replaced, the gas production rates were averaged. These rates were 900, 1,600, and 1,350 ml per liter of active volume per day for 20, 10, and 6.7 days detention, respectively. Statistical examination of these measurements showed that, within the 95-per cent confidence limits, these mean values were reproducible within ± 5.5 per cent.

The unit differences among the digesters with different loadings are apparent in these results. After the regular daily feed was stopped and digestion was allowed to continue under batch conditions the difference in behavior of the three digesters was even more marked. These experiments indicate that those units (A and B) which were digesting satisfactorily during the feeding cycle, reacted immediately to cessation of the daily raw sludge feed, and gas production rates at once started to drop.

With the sludge from C the initial rate of gas production was constant for the first five days of batch digestion. The gas yield was similar, during this period, to that during feeding. Later the daily gas yield decreased. The digesting sludge from the sewage treatment plant used as a seed for this investigation behaved similarly in batch digestion, except that a lower constant gas rate was obtained for the first seven days, followed by a rather sharp decrease. This observation can be seen in Figure 11.

These results may be interpreted as indicating that during feeding, Digester C was overloaded, and that the initial putrescible compounds or the intermediate products of degradation were stored in some manner in the digesting sludge.

Cumulative gas productions of 3,496, 5,396, and 11,604 ml for Digesters A, B, and C, respectively, were observed during 15 days of batch digestion.

The calculated reaction velocity constants k for the experimental digesters and control were all about 0.3. This was confirmed by plotting the theoretical curves calculated from Equa-

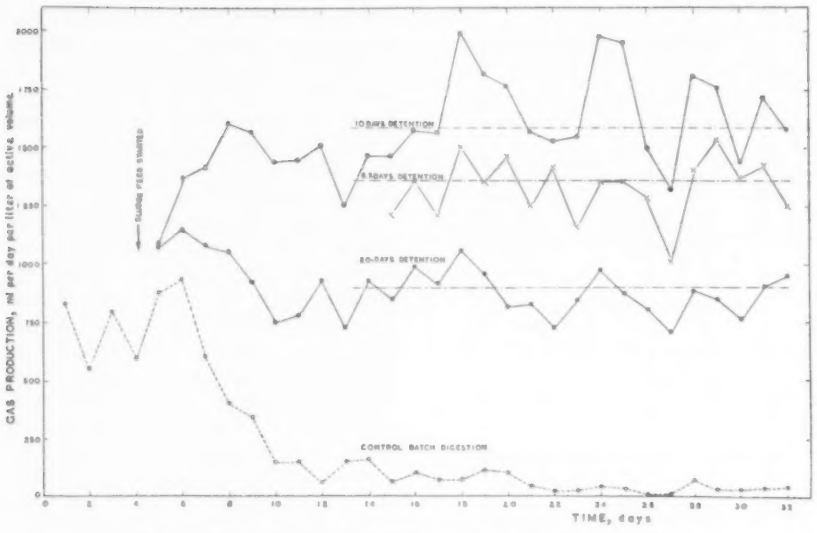

FIGURE 11.—Rate of gas production during feeding period.

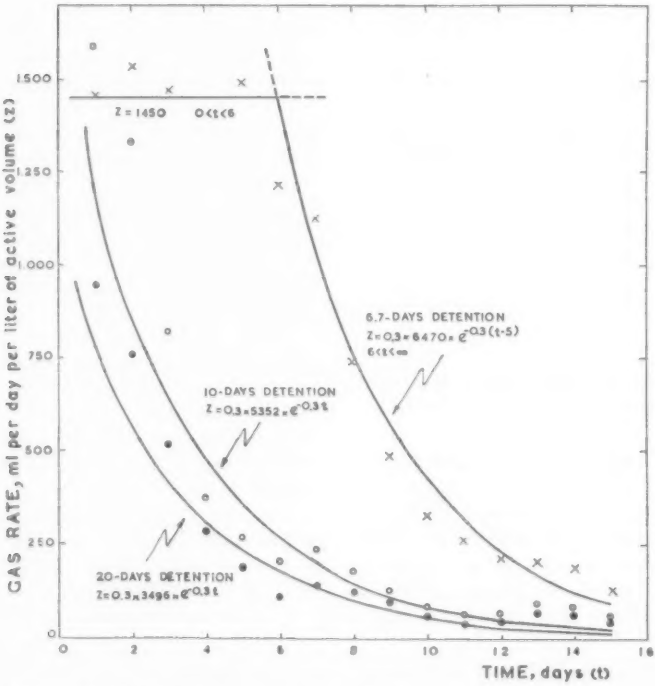

FIGURE 12.—Comparison between experimental and theoretical gas production rates during batch digestion.

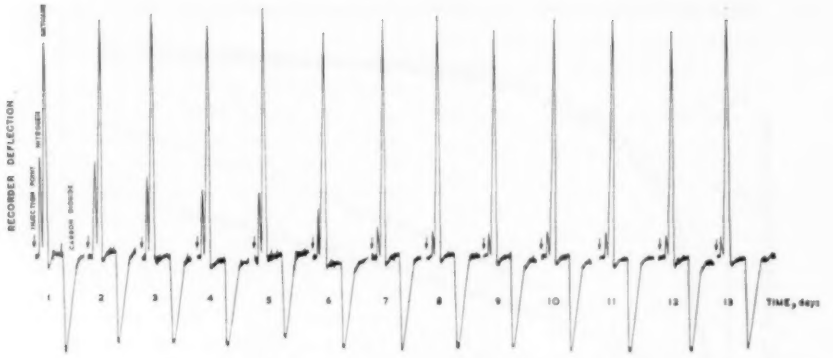

FIGURE 13.—Typical chart from gas chromatographic analysis of digester gas during feeding period.

tion 7, with $k = 0.3$, through the experimental points (Figure 3).

In Figure 12 the experimental daily gas production rates are also compared with those calculated using $k = 0.3$.

Composition of the Gas

The relative concentrations of methane and carbon dioxide in the gas produced were determined by gas chromatography. A typical set of results from the gas chromatographic analysis obtained during some preliminary observations is shown in Figure 13. The comparatively small variations in carbon dioxide content of the gas from digesters A, B, and C, and from the control are shown in Figure 14.

There appears to be no marked difference in the composition of the gas from any of the digesters. The relative concentration of methane was in the range of 70 to 79 per cent by volume, carbon dioxide between 21 and 30 per cent, and there were traces of nitrogen. These variations in gas composition could be due to experimental errors. The presence of nitrogen was possibly due to entry of air to the digesters. From Figure 13 it may be seen that there was an appreciable concentration of nitrogen present during the starting period of digestion

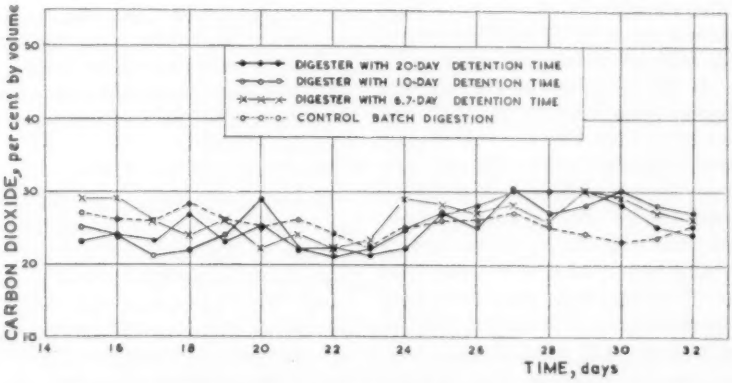
DIGESTER WITH 20-DAY DETENTION TIME
DIGESTER WITH 10-DAY DETENTION TIME
DIGESTER WITH 6.7-DAY DETENTION TIME
CONTROL BATCH DIGESTION
CARBON DIOXIDE, per cent by volume
TIME, days

FIGURE 14.—Composition of fermentation gas.

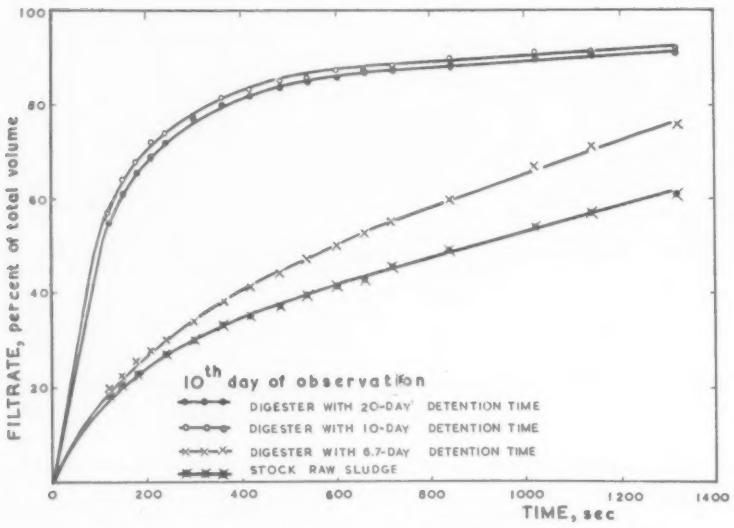
FILTRATE, percent of total volume
TIME, sec
10th day of observation
DIGESTER WITH 20-DAY DETENTION TIME
DIGESTER WITH 10-DAY DETENTION TIME
DIGESTER WITH 6.7-DAY DETENTION TIME
STOCK RAW SLUDGE

FIGURE 15.—Filterability results of raw and digested sludge.

and that this disappeared during digestion by dilution in the fermentation gas.

Filterability

The ease with which the raw and digested sludge might be expected to dry was determined by filterability tests, previously described. It is not possible to give all the filterability curves obtained during these experiments. There was appreciable variation from one test to another. Figure 15 gives a series of filterability curves which may be considered representative. In these curves the filterabilities of sludges withdrawn on the 10th day of digestion from Digesters A, B, and C are compared with that of raw sludge. Digesters A and B produced digested sludge with a similar filterability; the filterability of the sludge from Digester C was well below this value. The raw sludge had the poorest drying properties. It may be of interest to note that most of the filterability results followed this pattern. In general, erratic filterability results were obtained during the period before the digesters reached their more or less stable operating conditions.

Discussion

The results obtained from these laboratory studies cannot be assumed to be representative of plant-scale conditions. It is not to be expected that operating criteria can be extended in this way and it is unlikely that feeding, mixing, and temperature can be so closely controlled as in the laboratory. Nevertheless, some information obtained from these laboratory studies may be useful for treatment practice.

Optimum Detention Time

For these laboratory studies the 10-day detention time, which corresponds to 10-per cent daily sludge exchange, was the optimum for digester performance. This conclusion was supported by the analyses of the decomposition of the organic matter (Table II), which show similar characteristics for

digested sludge from the 20-day and 10-day digesters.

It is observed from Figure 11 that the organic loading of Digester B, although double that of A, produces about twice the gas of that coming from A. The filterability tests (Figure 15) show that, under laboratory conditions, digestion for 20 days produces a sludge no more easily dried than that from digestion for 10 days. The composition of the sludge gas was similar from these two digesters (Figure 14) and they behaved in a similar manner during the investigation (Figures 8 and 9). The general evidence, therefore, supports the view that, under the conditions here reported, 10 days was the optimum detention time.

According to published studies (1) (3) (5), it appears that high-rate digestion units can be operated safely using 10-days' detention period, without appreciable sacrifice of gas production or deterioration of sludge quality. It would, however, be difficult to operate with much shorter detention times.

A detailed examination of the behavior of Digester C, with a detention time of 6.7 days (Figure 10), shows evidence of overloading. The chemical composition of the digested sludge (Table II) and the filterability properties (Figure 15) were different from those of sludges from Digesters A and B. Rates of gas production during the period of daily feeding (Figure 11) were substantially lower, Digester C yielding only about one-half of what might have been expected from the gas-volume ratio of Digester A. This confirms the belief that gasification of the sludge solids is reduced at organic loadings greater than the optimum. It seems reasonable to conclude, also, that the instability of Digester C and the deterioriation in the quality of its digested sludge were also due to organic overloading.

This overloading with organic matter is also confirmed by the batch digestion observations (i.e., after the daily feeding was stopped).

Reaction Velocity Constant

It is known that the first order equation quite closely describes the anaerobic digestion process during the active growth period. If the volume of seeding material is sufficiently large in proportion to the putrescible organic matter to be digested it can be expected that there will be no lag phase and that the reaction will at once start to follow the first order equation.

The breakdown of organic matter by anaerobic digestion is governed by many factors, some of which cannot adequately be considered specifically in the present state of knowledge. It appeared to the authors, therefore, that gas production gave a satisfactory measure of digestion as a mass phenomenon. The course of production of both methane and of carbon dioxide can also be formulated in accordance with the first order equation (14).

It is to be expected that similar conditions of seeding, mixing, temperature, etc., will produce similar microbiological populations and, hence, similar biochemical behavior during digestion, and a similar reaction velocity constant.

The value of the reaction velocity constant k found in this study was 0.3.* This value was higher than the k-value estimated by Fair and Moore (14) for the autocatalytic part of the curve ($K_2 = 0.073$ at 95°F), or the k-value from a recent study by Schulze (7) where k was found to be approximately 0.14 at 32°C, or K of about 0.109 as obtained by Grune *et al.* (15) at 90°F. The agreement of the observed gasification results with values predicted from the first order equation with the k-value

* Constant k is reported as natural logarithms; K is based on common logarithms.

of 0.3 is demonstrated by Figures 3 and 12. Observation of the effect of previous feeding conditions on the digesters' behavior during short batch digestion showed cumulative gas productions of 3,296, 5,352, and 11,607 ml for 5, 10, and 15 per cent daily sludge exchange.

The results (Figure 3) for Digesters A and B show that the previous feeding conditions do not affect the cumulative gas production which is governed by the organic loading, the reaction velocity constant being 0.3 for each curve. The theoretical curve for Digester C, however, does not fit the measured results with $k = 0.3$ nor with $k = 0.19$, these two theoretical curves falling approximately on each side of the plotted measurements. A glance at Figure 12 will show the reason for the apparent variation in the value of k from Digesters A and B to that from C: the gas production in C after cessation of feeding took place in two stages.

During the digestion of organic matter in well-mixed anaerobic conditions the first-stage degradation to volatile acids and the production of methane are taking place at the same time. Efficient functioning depends on the rate of methane production at being least abreast of the acid production. Otherwise, acid will accumulate to some critical concentration, above which the activity of the methane producers will be interfered with or even completely inhibited. This interference, of course, aggravates the situation by leading to a more rapid accumulation of acids. It is clear, therefore, that the balance between acid formation and gas production is a critical factor in anaerobic digestion (7).

Since the methane is produced from the volatile acids, gas production can also be reduced by a decrease in the rate of production of these acids. If this is the case, organic matter may be stored in a form other than volatile acid and increase of these intermediate products could also limit the rate of gas production.

Such overloading and consequent storage, whether it be in the form of volatile acid or other intermediate product, is clearly indicated by the horizontal portion of the curve for Digester C, for the time up to about 5 days, in Figure 12—which is for batch digestion. The gas production from Digester C may be represented by the horizontal straight line followed by an exponential curve. It will be seen that this exponential portion of the curve can be quite closely fitted by the first order equation with $k = 0.3$ and assuming the gas production G as 6,470 (*i.e.*, the total of 11,604 ml less the amount produced during the first 5 days). Similarly, the exponential portion has been replotted in Figure 3 with $t' = t - 5$ days, $k = 0.3$, and $G = 6{,}470$.

Similar phenomena were observed with the gas production curves during the control batch digestion of the sludge used for the original seeding. The two control digesters produced results of such similarity that only one set of results is shown in Figures 11 and 14. It would be seen, therefore, that the digestion unit from which the seed sludge was drawn was somewhat overloaded.

Test for Overloading

It has been possible to follow the progress of gas production in laboratory-scale digesters after feeding was stopped in what is called batch digestion. It should be possible, in the same way, to remove a sample of digesting sludge from a full-scale digester and set up this sample in a laboratory digester at the same operating temperature. Observation of the gas production from this laboratory digester could then be used as a means

of determining the state of the full-scale digestion.

Sludge removed from a digester with adequate detention will show gas production following the first order reaction with the daily rate at once falling off. Sludge from an overloaded unit would show an approximately constant daily gas production rate for a few days before beginning to fall off. The number of days before the exponential die-away commenced could then be used as the measure of overloading.

Gas Composition

In these studies gas chromatography was used to follow the changes in the composition of the gas produced by the digesters with different detention times. The ionization detector was an effective tool for these gas chromatographic observations. Argon as a carrier gas permitted detection of the gases produced by fermentation or those remaining from the air originally in the digesters or accidentally introduced later. The method used allowed the determination of hydrogen, nitrogen, methane, and carbon dioxide during a single analytical procedure. A higher sensitivity of the ionization detector for hydrogen and nitrogen than for carbon compounds was observed (Figure 6). The value of a series of gas chromatographic observations has been demonstrated for following the course of anaerobic digestion (Figure 14). A similar conclusion was recently reported by Grune *et al.* (15)(16) from studies of the effects of some radiochemical materials on anaerobic digestion. Thermoconductivity cells were successfully used in those studies as a gas chromatographic detector.

The relative concentration of methane was found to lie in the range of 70 to 79 per cent by volume, carbon dioxide between 21 and 30 per cent (Figure 14), and there were traces of nitrogen. These variations could, however, be due to experimental errors.

It was to be expected that the similar bacterial populations in each of the digesters would, under similar experimental conditions, produce fermentation gases with similar compositions. In a heterogeneous culture, however, such as that found in anaerobic digestion, it is likely to be difficult to predict the possible effects of organic overloading, but it is apparent from Figure 14 that there was no difference in the gas composition from the various digesters.

The amount of methane observed in the fermentation gas was in the range commonly reported elsewhere. The slightly higher values may be attributed to the excellent mixing and consequent homogeneity of the reacting materials in these studies. From these observations it may be concluded that an increase of methane content over that commonly achieved in fermentation gas cannot be produced by a closer contact of digesting sludge with the gas phase. This observation is in accord with the general biochemistry of methane fermentation. Perhaps a more drastic change of the conditions under which the sludge is digested would have to be provided for obtaining a more economical ratio of methane to carbon dioxide (17).

As may be seen from Figure 13 the small amount of nitrogen, which was present at the start of the digester operation owing to incomplete evacuation of air, disappeared during the process. As was expected, oxygen was not present in the digester gas.

Filterability

Filterability of sludge is affected by many factors (18)(19). The raw sludge used in these studies was stored frozen and it can be assumed that the filterability of this sludge was greatly improved (20) and this will educe the

apparent improvement in filterability resulting from digestion. As may be seen from Figure 15 the filterability characteristics of sludge produced by the 10-day and 20-day digesters were similar. It is well-known and generally accepted, that as sludge becomes more stable; i.e., as the putrescible matter is destroyed and gasified, the ease with which the sludge can be dried increases. The similar filterabilities of sludges with 20- and 10-day detention suggest that organic matter degradation, decomposition of colloidal substances, and stabilization of putrescible matter were similar in both digesters. The filterability of sludge from 6.7-day detention was well below the other values. Measurements of filterability appeared to support the conclusion that 10-day detention was the optimum for the particular conditions of the experiment and that 6.7-day detention caused overloading of the digestion unit.

Summary

1. A series of laboratory sludge digestion units were operated within the mesophilic zone of temperature with detention times of 6.7, 10, and 20 days. The digesters were fed once daily with raw sewage sludge with 3.14-per cent total solids. The conditions of the experiments allowed complete mixing of the digester contents and close contact of digesting sludge with the gas phase. From the results of these experiments the conclusion may be drawn that the most efficient performance of the digester was reached with 10-day detention. The digester with 6.7-day detention showed symptoms of overloading. The efficiency of the digester was judged on the basis of the destruction of volatile matter introduced into the digesters, gas production, reaction velocity constants, and physical characteristics of the digested sludge.

2. Rotating laboratory digesters were found convenient to carry out these experiments and pressure measurements at constant conditions proved satisfactory for the calculation of gas production data.

3. No appreciable difference could be noted in the results of the destruction of organic matter of sludges obtained from 20- and 10-day retention, while a 6.7-day displacement period produced sludge with poorer characteristics. Gas production rates of about 900, 1,600, and 1,350 ml per day per liter of active volume were observed for 20-, 10-, and 6.7-day retention, respectively.

4. Observation of the effect of previous feeding conditions on the digesters' behavior during short batch digestion showed gas productions of 3,496, 5,352, and 11,604 ml for 5, 10, and 15 per cent of daily sludge exchange; the calculated reaction velocity constants k for these digesters and blank control were all about 0.3 (base e). However, the daily gas production curve for the 15-per cent digester (C) showed a horizontal straight line portion followed by an exponential curve. These results suggest that measurements of the rate of gas production during batch digestion after cessation of the regular daily feed may give significant information about the digester behavior.

5. Gas adsorption chromatography was employed for analysis of the fermentation gas. Equipment with a strontium-90 beta radiation ionization chamber for gas chromatographic detection was adopted for these studies and argon was used as the carrier gas. The value of a series of gas chromatographic observations has been demonstrated for following the course of anaerobic digestion.

6. There was no significant difference in the quality of the gas produced from any of the digesters in daily feeding or batch conditions. From gas chromatographic analyses the methane concentration was found to lie

in the range of 70 to 79 per cent by volume; carbon dioxide, 21 to 30 per cent; and there were traces of nitrogen. These variations, however, are quite possibly due to experimental errors. Therefore, it appears that increase of methane content in fermentation gas cannot be achieved by more close contact of the digesting sludge with the gas phase. More drastic change of the conditions under which the sludge is digested would have to be provided for obtaining a more economical ratio of methane to carbon dioxide.

7. Under the laboratory conditions of these studies, the digestion of sludge on a 20-day detention basis produced no better filterability of the digested sludge than that obtained from a sludge with a 10-day detention period. The filterability of a sludge from 6.7-day detention was well below these values. Most of the filterability results followed this pattern but variations did occur. Measurements of filterability appeared to support the conclusion that a 10-day detention time was the optimum for the particular conditions of the experiment.

Acknowledgments

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SEDIMENTATION AND PREAERATION EXPERIMENTS AT LOS ANGELES *

By Robert J. Theroux † and Jack M. Betz

Respectively, Project Engineer, Hyperion Engineers, and Senior Civil Engineer, Sewage Treatment Division, Los Angeles, Calif.

As a prelude to the enlargement of Los Angeles' (Calif.) Hyperion sewage treatment plant from a 245- to a 420-mgd facility, it was necessary to answer the following questions:

1. How does the weir overflow rate affect the performance of the primary sedimentation tanks?
2. What is the limiting loading rate for the sedimentation tanks?
3. How much benefit is derived from preaeration?

To answer these questions and thus obtain design information, several sedimentation and preaeration experiments were performed at the Hyperion plant. The results of these tests are reported and discussed in this article.

The existing Hyperion plant includes facilities for screening and grit removal. After passing through these units, the flow enters the two preaeration tanks. These are two-pass tanks, each pass being 300 ft long, 15 ft deep, and 30 ft wide. The detention time at the average flow of 245 mgd is 25 min. After preaeration the sewage enters the eight primary sedimentation tanks. Each of these tanks is 300 ft long, 15 ft deep, and 57.5 ft wide. The detention time at the design average flow of 245 mgd is 1.5 hr. The secondary treatment facilities were of no concern in the test program discussed here.

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† At the present time, Supervising Engineer, Water and Sewage Department, Koebig and Koebig.

Weir Overflow Rates

To answer the first question, one of the settling tanks was selected for test purposes and about 40 per cent of its weir length was blocked off. The weirs in the existing tanks begin at a point about one-third of the tank length from the outlet end and are arranged both parallel and perpendicular to the direction of flow. Blocking of the weirs caused an increase in the weir loading from the original design figure of 40,000 gpd/ft to about 70,000 gpd/ft. This latter rate approximately corresponds to the weir loading which would be experienced at the increased design flow of 420 mgd if no additional settling capacity were provided.

An identical, unmodified tank was used for control purposes. Effluent samples were collected every two hours

TABLE I.—Effect of Weir Length on Suspended Solids Removal

Date (Oct. 1955)	SS (mg/l)			
	Influent		Effluent	
	Short Weir Tank	Long Weir Tank	Short Weir Tank	Long Weir Tank
19	—	—	202	239
20	—	—	169	201
21	—	—	202	219
22	—	—	149	154
23	—	—	117	118
24	496	503	91	97
25	570	601	215	242
26	567	564	190	187
Avg	544	556	167	182

from both tanks and analyzed for suspended and settleable solids. Similar samples were taken from the flow entering the two tanks (which comprised a mixture of raw sewage and waste activated sludge) to verify that the solids loadings on the two tanks were approximately equal. The presence of the waste activated sludge in the influent samples explains both the high suspended solids values and the high removal efficiencies shown in Table I.

The experiments showed a removal of suspended solids of 69 per cent for the short weir tank and 67 per cent for the long weir tank. From these results there appears to be no obvious advantage, as far as suspended solids removal is concerned, in using the longer weirs.

This conclusion is in line with operating results of many treatment plants as shown in Figure 1. These data indicate that the weir loading itself has no effect on suspended solids removal efficiencies in the range of 40,000 to 70,000 gpd/ft. Babbitt and Baumann (1) state that weir overflow rates should not exceed 200,000 gpd/ft and preferably be less than 50,000 gpd/ft, thus indicating no great concern over high weir overflow rates.

These loading rates are greatly in excess of recommendations contained in the "Ten State Standards" (2) which state that weir loadings should not exceed 15,000 gpd/ft. For activated sludge settling tanks, Anderson (3) recommends a maximum rate of 20,000 gpd/ft.

Considered rationally, it is difficult to establish a basis for assuming that

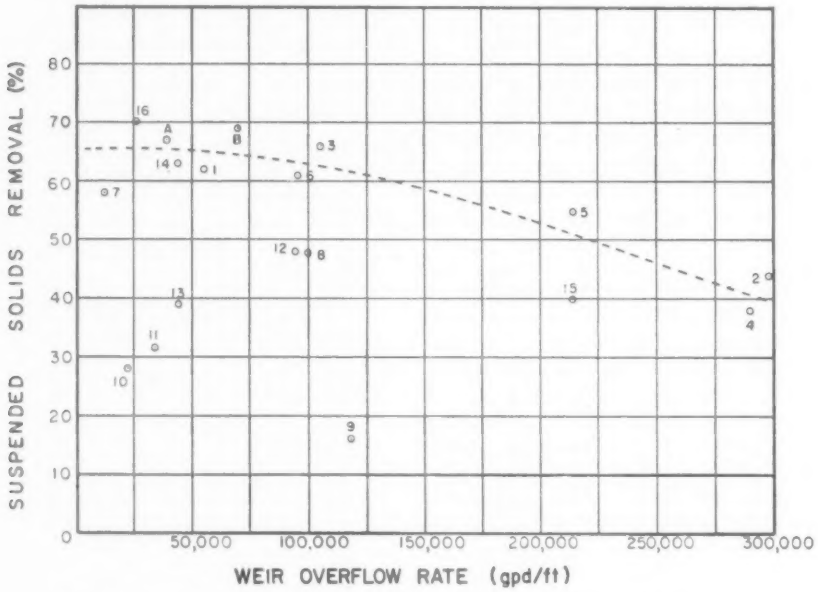

FIGURE 1.—Weir overflow rates and suspended solids removals at 17 sewage treatment plants.*

* Legend:

1. Hartford, Conn.
2. Detroit, Mich.
3. Racine, Wis.
4. Bowery Bay, N. Y.
5. Tallman Island, N. Y.
6. Fort Wayne, Ind.
7. Marshalltown, Pa.
8. Kenosha, Wis.
9. Jackson, Mich.
10. Hammond, Ind.
11. 26th Ward, N. Y.
12. Hunts Point, N. Y.
13. Abington, Pa.
14. Portsmouth, Va.
15. Canton, Ohio
16. Niles, Mich.
- A. Hyperion, Los Angeles, Calif.
- B. Hyperion, Los Angeles, Calif.

weir loadings can affect the tank effluent. The exception, of course, would be where the weirs were so concentrated that a rising velocity would be created which would exceed the settling velocity of the sludge. The increase of the approach velocity at the tank surface should not result in the discharge of any additional material. Weir location may be considerably more important than weir loading.

Solids Removal

The second question concerns the determination of settling efficiencies which would prevail if the flow to the eight existing tanks were increased to 420 mgd. For this experiment the inlet facilities of one tank were modified so that the flow to the tank was approximately equal to ⅛ of 420 mgd, the latter being the future design average flow. The diurnal flow variation at Hyperion is such that a dry weather peak flow rate of 75 mgd per tank, an average flow of 52.5 mgd per tank, and a minimum flow of 21 mgd per tank correspond to the assumed design conditions for a 420-mgd average flow. Suspended solids and settleable solids tests were performed on 2-hr influent and effluent samples.

Settleable Solids Removal

When the rate of flow through the tank exceeds 38 mgd (which corresponds to a velocity of approximately 4 fpm), the amount of settleable solids in the effluent starts to rise rather sharply. This is demonstrated in Figure 2. The influent settleable solids at Hyperion are normally on the order of 12 ml/l and the effluent solids are normally less than 0.05 ml/l.

A further experience similar in nature to that at Hyperion was recorded at the Los Angeles Valley Settling Basin. This facility is a chemical treatment plant employing aluminum sulfate as a coagulant. The two settling tanks are each 300 ft long, 17.5 ft wide, and 10 ft deep. At this plant it was found that a velocity through the tank in excess of 4 fpm resulted in a marked increase in the effluent settleable solids. The performance of the Valley Settling Basin is shown in Figure 3.

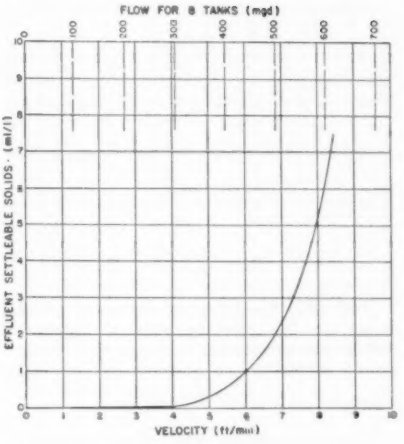

FIGURE 2.—Effect of flow-through velocity on the settleable solids concentration.

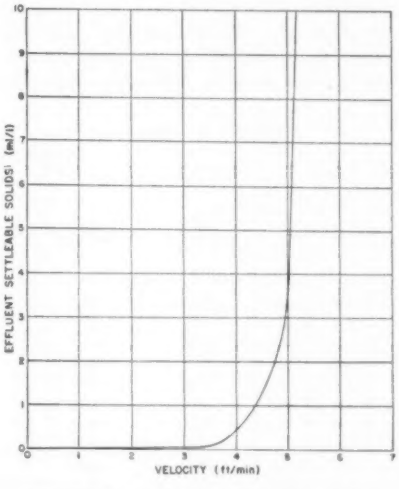

FIGURE 3.—Effect of flow-through velocity on the settleable solids concentration at the Los Angeles Valley Settling Basin.

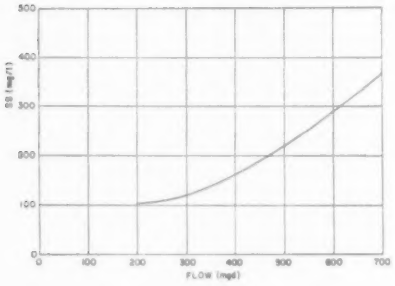

FIGURE 4.—Effect of increased sewage flows on the primary effluent suspended solids concentration.

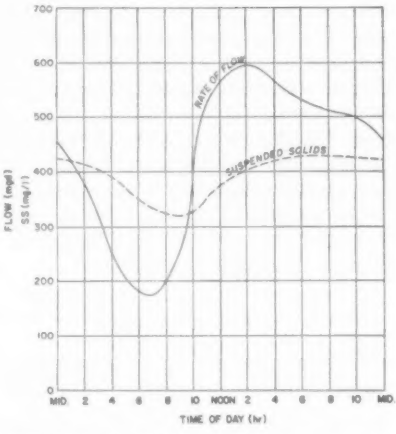

FIGURE 5.—Daily variation in flow and influent suspended solids.

Suspended Solids Removal

Figure 4 shows the concentration of suspended solids in the effluent from the existing tanks at various flows. Figure 5 depicts the diurnal flow and influent suspended solids variations.

In evaluating the effectiveness of suspended solids removal it is necessary to keep in mind that the suspended solids in the raw sewage are at a minimum when the flow is at a minimum and that they are highest throughout the long period in which the flow is above average. Thus an unfavorable removal of suspended solids during the long period of high flow is particularly unfortunate because it is during this time that the suspended solids loading is the highest. The quantities of suspended solids which would be in Hyperion's primary effluent when the average flow is 420 mgd are shown in Table II. These same data are also shown graphically in Figure 6. In this figure the area between the two curves represents the amount of suspended solids removed. It appears that an average of 46 per cent of the suspended solids would be removed by operating the sedimentation tanks at the future design flow rate of 420 mgd. Inasmuch as earlier

TABLE II.—Estimated Suspended Solids Inventory at Future Average Design Flow of 420 mgd

Time Period	Flow Rate (mgd)	Flow (mil gal)	Raw Sewage SS		Primary Effl. SS	
			(mg/l)	(lb)	(mg/l)	(lb)
11 PM– 1 AM	483	40.3	425	143,000	210	70,500
1 AM– 3 AM	420	35.0	420	122,500	175	51,000
3 AM– 5 AM	325	27.1	405	91,500	135	30,500
5 AM– 7 AM	205	17.1	370	52,700	105	14,960
7 AM– 9 AM	173	14.4	335	40,200	100	12,000
9 AM–11 AM	250	20.8	320	55,500	110	19,100
11 AM– 1 PM	520	43.3	350	126,300	235	85,000
1 PM– 3 PM	588	49.0	390	159,000	280	114,500
3 PM– 5 PM	588	49.0	410	167,500	280	114,500
5 PM– 7 PM	545	45.4	425	160,500	250	94,500
7 PM– 9 PM	520	43.3	430	155,000	235	85,000
9 PM–11 PM	505	42.1	425	149,000	225	79,000

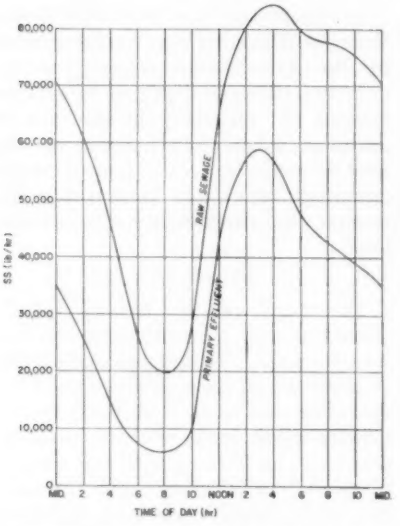

FIGURE 6.—Estimated inventory of suspended solids for a future design flow of 420 mgd. Data are from Table II.

tests (Table I) at existing flows showed that suspended solids removals approached 70 per cent, it was concluded that additional settling tanks would be necessary if good efficiency is to be maintained under conditions of increased sewage volumes.

The existing primary tanks were originally designed on the basis of an overflow rate of 1,800 gpd/sq ft with a detention time of 1.5 hr at a sewage flow rate of 245 mgd. With the flow at 420 mgd the overflow rate is 3,100 gpd/sq ft, the detention period is approximately 0.88 hr, and the flow-through velocity is 5.8 fpm.

Discussion

It is apparent from the test data that there exists for a settling tank a critical loading, beyond which, small increases in loading are accompanied by large reductions in removal efficiencies.

Tank loading is usually expressed in terms of either detention period or surface overflow rate. Figure 7 shows a

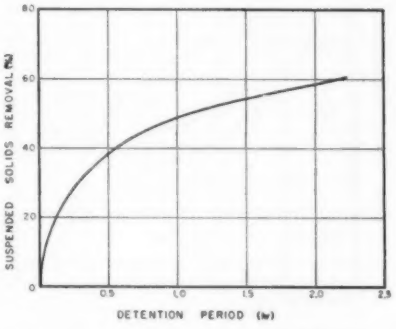

FIGURE 7.—Relationship between suspended solids removal and detention period (after Imhoff and Fair).

common relationship between removal efficiency and detention period (4) which demonstrates clearly the action of the law of diminishing returns, but it does not show any particularly critical loading limit as implied above. However, in Figure 8, which is a plot of the data in Table II, the critical loading limit is clearly evident.

If loadings for tanks having the dimensions of the Hyperion primary settling tanks were expressed in terms of surface loading, Curves A and B in Figure 9 would result. Curve A is based on the results shown in Table II. Curve B is based on the plot of detention period vs. efficiency from Imhoff and Fair (4) expressed in terms

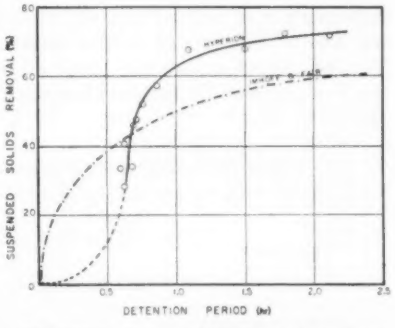

FIGURE 8.—Relationship between suspended solids removal and detention period at Hyperion.

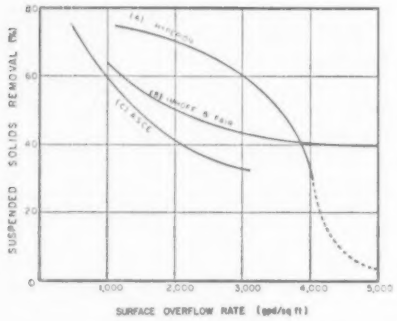

FIGURE 9.—Relationship between suspended solids removal and surface overflow rate.

of the corresponding surface loading rate at Hyperion. Curve C is a direct plot of data from the FSIWA manual of sewage treatment plant design (5).

For tanks of some different proportions, curves of test results may correspond very closely to the curve in Figure 7. Actually, the main point here is that commonly accepted relationships may not always have general application and that in view of this, other indicators of performance must also be considered. All facts considered, it is felt that the longitudinal velocity is the most useful measurement that can be used to determine the critical loading of the Hyperion tanks. The effect of the tank velocity on the effluent quality as shown in Figure 2 is believed caused by the resuspension of sludge and the resulting loss of this sludge in the effluent. This phenomenon was also observed at the Los Angeles Valley Settling Basin (6).

In other cases, i.e., for other tanks, the critical loading may be determined by the flow-through velocity, or by detention time and depth, or by surface loading (7) especially in the case of granular solids. Turbulence at the inlet or outlet end of a tank or short circuiting could also conceivably determine the critical loading for a given tank.

Preaeration

The third question relates to the effectiveness of preaeration at the Los Angeles plant. To measure the benefits of preaeration, data were obtained by operating one battery of the primary sedimentation tanks without preaeration and one battery with the normal 25 min of preaeration. Effluent samples were taken from both batteries and the analytical results are shown in Table III. The data indicate that preaeration did not improve removal of either settleable solids, suspended solids, or BOD, or reduce the chlorine demand. There was, however, some improvement in dissolved sulfide and grease removal. Laboratory-scale experiments on Hyperion sewage show that the improvement of grease removal attributed to preaeration occurs in the first 10 min of application.

The value of the oxidation-reduction potential at each stage of treatment is shown in Figure 10 (8) and it can be seen that the ORP of the raw sewage is in the anaerobic zone. Preaeration raises the ORP to the facultative zone, but following primary sedimentation it is back in the anaerobic zone again. This earlier work (8) indicates

TABLE III.—Comparison of Preaerated with Non-Aerated Primary Effluents

Test Period	Settleable Solids (mg/l)		SS (mg/l)		BOD (mg/l)		Diss. Sulfides (mg/l)		Cl_2 Demand (mg/l)		Grease (mg/l)	
	Pre.	Non.	Pre.	Non.	Pre.	Non.	Pre.	Non.	Pre.	Non.	Pre.	Non.
12/6/54 to 2/22/55	—	—	168	162	166	142	—	—	—	—	—	—
3/2 to 7/31/55	—	—	193	162	196	180	0.48	0.87	30	31	—	—
3/13 to 4/5/56	12	12	251	272	—	—	0.20	0.29	—	—	42	47

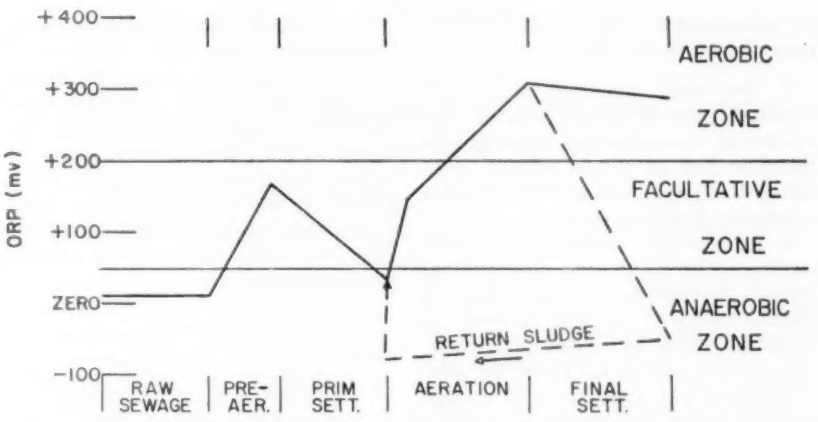

FIGURE 10.—Oxidation-reduction potentials at the Hyperion plant.

that due to the characteristics of the Hyperion sewage (extremely low ORP and high oxygen demand) preaeration results in no marked benefit to the later treatment steps.

One other observation of pertinence is the removal of grit in the preaeration tanks. The grit removed here is that which passes through the controlled-velocity grit chambers. Considering this secondary removal of grit to be an indicator of the efficacy of aerated grit chambers, it would appear that the use of such a chamber in the enlarged Hyperion facilities would be beneficial. In addition, there seems to be a good chance that such a chamber would also produce some of the limited benefits (grease and sulfide removal) which now accrue to preaeration. The reason for this is that these benefits essentially are the result of a very brief period of aeration.

In a search for published information with which to compare the Hyperion results, only a small amount of data was found. However, Roe (9) in 1951 published a rather complete discussion of the subject, based on information received from 51 plants. The data reported by Roe (9) and the results obtained at Hyperion are compared in Table IV.

Summary and Conclusions

Full-scale experiments were performed at the Los Angeles sewage treatment plant to collect operating data with which to guide the design

TABLE IV.—Effect of Preaeration on Various Treatment Factors

Factor	Roe (9) Conclusion	Hyperion Conclusion	Agreement
ORP	Establishes positive ORP	Establishes positive ORP	Yes
H_2S	Entrained H_2S removed	30–50% reduction in dissolved H_2S	Partial
Grease	Removal increased to 60% or better	Slight improvement	Partial
SS	Removals approximately doubled	No significant effect	No
BOD	No significant effect	No significant effect	Yes
Chlorine demand	Not reported	No significant effect	—
Grit separation	Accomplished effectively	Accomplished effectively	Yes

of enlargements. The results of these tests demonstrated that:

1. Treatment efficiency at a weir overflow rate of 70,000 gpd/ft was similar to that obtained using a weir overflow rate of 40,000 gpd/ft, indicating that weir loading itself is not a significant factor at Hyperion.

2. A primary sedimentation tank loading which results in a longitudinal velocity exceeding 4 fpm causes a marked decrease in the removal of settleable solids and suspended solids. The performance of the Hyperion sedimentation tanks, which are 300 ft long, does not follow the commonly observed relationships based on detention time and surface loading because at high loadings the longitudinal velocity causes resuspension of solids.

3. Preaeration at Hyperion does not improve the removal of settleable solids, suspended solids, or BOD, nor reduce the chlorine demand. Preaeration does improve removal of dissolved sulfides, grease, and grit, and has the temporary effect of increasing the ORP.

As a result of the Hyperion experiments, additional sedimentation tanks were designed to: (a) maintain an average longitudinal velocity of less than 4 fpm; and (b) maintain an average weir overflow rate of no more than 70,000 gpd/ft. No new preaeration facilities are to be provided, but a limited amount of aeration will take place in the aerated grit removal tanks.

Acknowledgments

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STUDIES OF A ZOOGLEAL FORMING ORGANISM FOUND IN ACTIVATED SLUDGE

By T. C. Buck and C. E. Keefer

Research Bacteriologist, and Sewerage Engineer, Bureau of Sewers, Baltimore, Md.

Most investigators of the activated sludge process agree that the biochemical reactions due to the bacteria in activated sludge play a major role in the process. The historic work of Butterfield (1) in 1935 in isolating the organism *Zoogloea ramigera* was a major step forward in the study of the activated sludge process. Further studies of this organism were made by Heukelekian and Littman (2), Wattie (3), and McKinney and Horwood (4). Additional investigations have been conducted at the Back River sewage treatment works, which serves the major portion of the city of Baltimore, for the purpose of isolating other organisms associated with the activated sludge process.

A zoogleal forming organism has been isolated from the activated sludge at the Back River plant. Although this organism is similar to *Zoogloea ramigera* as reported by Butterfield and other investigators, it has a sufficient number of morphological, biochemical, and physiological differences from *Zoogloea ramigera* to warrant the belief that it is of the same genus but of a different species. That it plays an important role in the activated sludge process is evidenced by the fact that it materially reduces the biochemical oxygen demand of aerated sewage.

Method of Isolation

The sludge used in conjunction with these studies was collected from activated sludge units, which treat approximately 20 mgd of primary settling tank effluent. The theoretical detention period is about 5 hr in the aeration tanks and about 2.4 hr in the final settling tanks. The activated sludge was collected from time to time as it flowed from the final settling tanks. At no time during the investigation was the sludge in a bulked condition.

For several weeks during the beginning of the investigation many attempts were made to isolate *Zoogloea ramigera* from the activated sludge. Butterfield's method, which consisted of inoculating serially various broths with and without aeration, was tried without success. Platings, which were made on different media, were usually overgrown in 48 hr by other organisms. When these organisms were picked and transferred to various broths, no flocks formed whether the broths were aerated or not.

Finally, after using a number of media, the zoogleal organism herein discussed was isolated by inoculating and aerating modified Tyrod's broth and Tyrod's agar. The broth contained the following ingredients, which were sterilized separately:

Ingredient	Amount
H_2O (distilled)	1,000 ml
NaCl	0.1 g
KCl	0.2 g
$CaCl_2$	0.2 g
$MgCl_2 \cdot 6H_2O$	0.1 g
$NaH_2PO_4 \cdot H_2O$	0.05 g
$NaHCO_3$	0.5±g
Gelysate	0.5 g
Dextrose	5.0 g

The quantity of $NaHCO_3$ used was such that the foregoing formula had a pH of 7.6. When transfers were

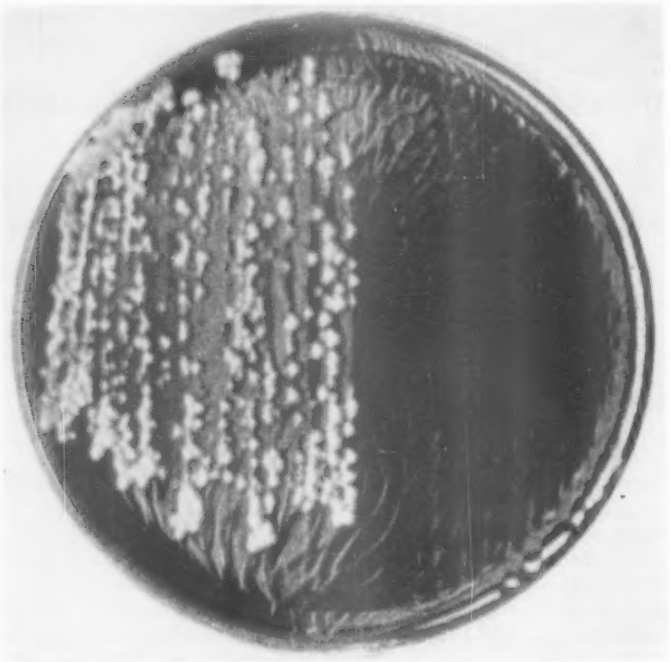

FIGURE 1.—Alcian blue nitrate agar plate, showing development of discrete colonies where plate was streaked with zoogleal organism and little growth where plate was streaked with coliform organisms.

made from 3,000 ml of aerated Tyrod's broth to modified Tyrod's agar, which was maintained at 30°C, pinpoint colonies formed after 72 hr. These colonies were transferred to the modified Tyrod's broth; and after an incubation period of 48 hr zoogleal masses formed and became attached to the sides of the tubes. This procedure of transfers was repeated 10 times to insure that the organism was in pure culture. Some of the zoogleal flocks in the broth were firmly pressed between two sterile microscopic slides to separate the organisms from their gelatinous matrix. Small portions of the freed organisms were transferred to agar plates for pure culture isolation.

Supplementary studies indicated that nitrate broth and nitrate agar were better media for studying the organism than Tyrod's broth and Tyrod's agar, in that quicker growth and larger colonies were obtained with larger zoogleal masses forming in the broth. The growth of the organism was also stimulated when it was grown on agar or in broth containing alcian blue. At the same time the growth of coliform organisms was inhibited. Figure 1 shows an agar plate containing alcian blue, one-half of which was streaked with the zoogleal organism and the other half with coliform bacteria. The zoogleal organism produced discrete colonies, whereas the coliform organisms produced very little growth.

Morphology

The morphological characteristics of the organism, which are listed in Table I, were studied when using a Leitz

microscope with a phase condenser. The organism is a non-motile, Gram-negative diplo bacillus with somewhat pointed ends. It was quite difficult to Gram stain. Burk and Hucker's method of staining produced only residual artifacts. The organism was finally stained by incorporating it in a glycerine-egg-albumin mixture. The average size of the organism is 1×5 μ. Although several methods were used to determine whether the organism was encapsulated, no capsules were observed. However, Figure 2 indicates that the organism is enveloped in a halo when magnified 1,500 times. This phenomenon was always observed in other photographs. When Tyrod's broth, to which alcian blue

TABLE I.—Morphological Characteristics of Zoogleal Forming Organism

Item	Observation
Staining vegetative cells	Difficult
Size (μ)	1×5
Ends	Round to pointed
Form	Diplobacillus
Motility (wet mount)	Non-motile
Flagella	No flagella when stained
Spore stain	Negative
Gram stain	Negative
Capsule stains	None observed when stained
Alcian blue stain	Polysaccharides present
Acid fast stain	Negative
Chains—6 cells	20-day culture, few observed
Endo bodies	20-day culture, motile bodies

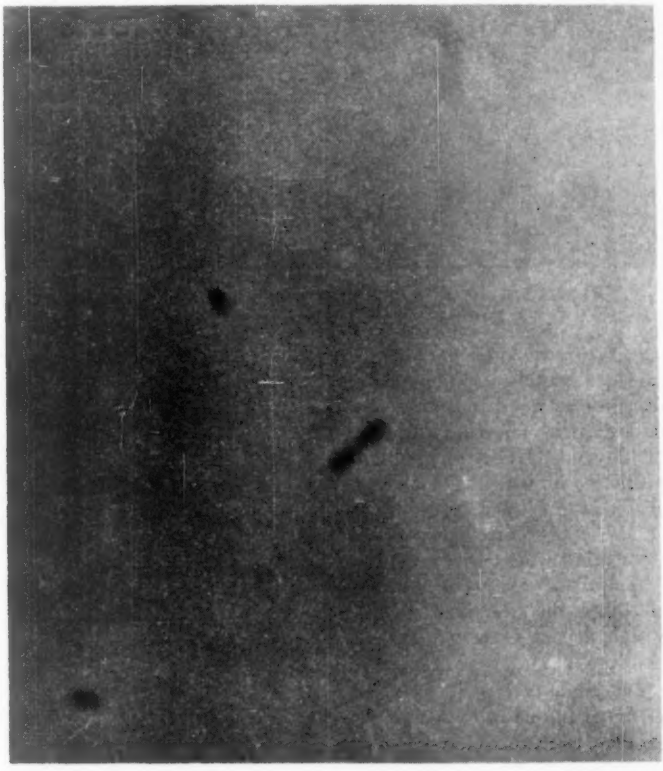

FIGURE 2.—Zoogleal organisms magnified approximately 2,000 times.

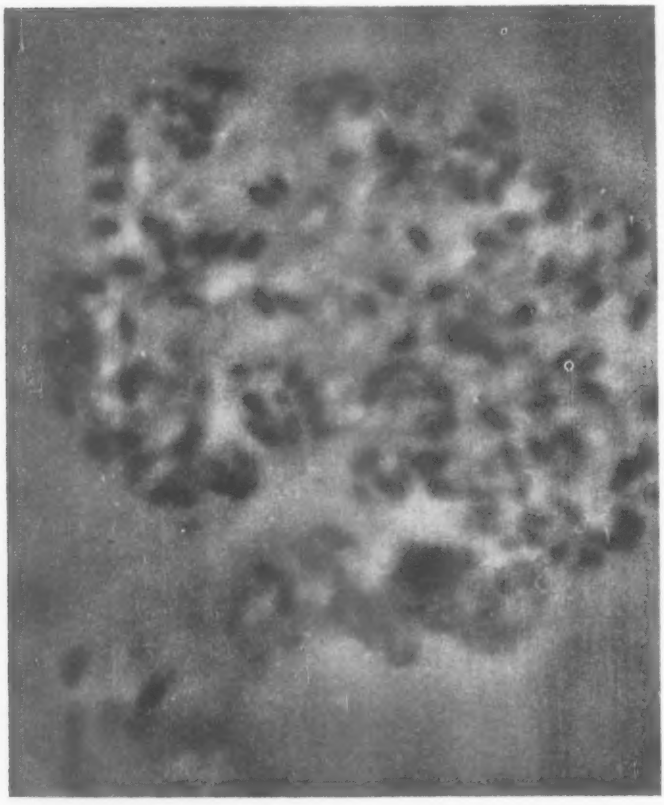

FIGURE 3.—Zoogleal organisms embedded in their matrix.

had been added, was inoculated with the organism, it was demonstrated that polysaccharides were produced (5). When the organism was grown in maltose for 20 days at 30°C, several chains of organisms, containing 6 cells, were observed. Large zoogleal masses formed and became attached to the sides of test tubes when the media was aerated. Figure 3 shows a zoogleal mass containing the organism. Endo bodies, which moved from one end of the cell to the other, were observed. Usually four such bodies of different sizes were noted in one cell. A number of these bodies were in the wet mount substrate outside of the mother cells.

Cultural Procedures

In preparing the various cultures of the organism, a number of broths were used. Of these, nitrate broth gave the best growth. When using nitrate agar, the entire colonies were translucent and were 2 mm in diameter. Four plates produced only surface growth. When deep stabs in nitrate agar were made, there was no growth deeper than a few millimeters below the surface. Gelatin was not liquefied by the organism.

Biochemical Reactions

The biochemical reactions produced by the organism are given in Table

II. The usual alcohols and saccharides were inoculated with the organism. The best growth was obtained when gelysate or trypticase peptones were added to the carbohydrates for the purpose of supplying amino acids and stimulating growth. When the organism was incubated at 30°C for 48 hr, the growth in all of the carbohydrates varied from 2+ to 3+, the pH varied from 7.2 to 7.4, and at the end of 20 days the growth ranged from 3+ to 4+ and the pH increased to 7.8 to 8.4. This increase in pH is in all probability due to the production of ammonia by the action of the organism on the peptone. Since no gas was produced, there was no cleavage of the carbohydrates.

Approximately 400,000 of the zoogleal organisms, which were in suspension in physiological saline solution, were injected into the inguinal region of the right leg of a guinea pig. No redness or swelling was observed after 1 and 10 days; the organism, therefore, was not pathogenic to guinea pigs.

Physiological Characteristics

The physiological characteristics of the organism are given in Table III. The organism is specifically an aerobe. However, when polysaccharides and gelysate were added to agar, growth as much as 3 mm below the surface of stab cultures developed. As a result of these observations, it is impossible to state whether the organism is an obligate aerobe. It may be possible to answer this question if a more suitable substrate can be developed.

TABLE II.—Biochemical Reactions of Zoogleal Forming Organism

Media	48 hr, 30°C				20 Days, 30°C			
	Growth	Acidity	pH	Gas	Growth	Acidity	pH	Gas
Alcohols:								
Adonitol	2+	–	7.2	–	3+	–	7.8	–
Dulcitol	3+	–	7.2	–	3+	–	7.8	–
Glycerol	3+	–	7.4	–	3+	–	7.8	–
Mannitol	3+	–	7.4	–	3+	–	7.8	–
Sorbitol	2+	–	7.4	–	3+	–	7.8	–
Inositol	2+	–	7.4	–	4+	–	8.4	–
Monosaccharides:								
Arabinose	2+	–	7.4	–	4+	–	8.4	–
Dextrose	2+	–	7.4	–	4+	–	8.4	–
Galactose	3+	–	7.4	–	4+	–	8.4	–
Levulose	2+	–	7.4	–	4+	–	8.4	–
Mannose	2+	–	7.4	–	4+	–	8.4	–
Rhamnose	2+	–	7.4	–	4+	–	8.4	–
Xylose	2+	–	7.4	–	4+	–	8.4	–
Disaccharides:								
Cellubiose	2+	–	7.4	–	4+	–	8.4	–
Lactose	2+	–	7.4	–	4+	–	8.4	–
Maltose	3+	–	7.4	–	4+	–	8.4	–
Melibinose	2+	–	7.4	–	4+	–	8.4	–
Saccarose	3+	–	7.4	–	4+	–	8.4	–
Trehalose	2+	–	7.4	–	4+	–	8.4	–
Polysaccharides:								
Dextrin	2+	–	7.4	–	4+	–	8.4	–
Inulin	3+	–	7.4	–	4+	–	8.4	–
Melezitose	3+	–	7.4	–	4+	–	8.4	–
Raffinose	2+	–	7.4	–	4+	–	8.4	–
Starches	2+	–	7.4	–	4+	–	8.4	–

TABLE III.—Physiological Characteristics of Zoogleal Forming Organism

Item	Observation
Aerobic	Depending on substrate
NO_3 reduction	+
N_2 gas	+
Chromogenic	None
IMVIC tests:	
Indol	−
Methyl red	−
Voges proskauer	−
Koser citrate	−
Urease	+
Catalase	+
H_2S	−
Litmus milk	Neutral to alkaline coagulation after 19 days; no putrefaction; no gas

Nitrates were reduced to ammonia with the production of gas. To determine the quantity and the analysis of the gas, several groups of tests were made. One of these consisted of inoculating 1,290 ml of standard nitrate broth with 10 ml of a solution containing the organism in pure culture and incubating the broth at 30°C for 48 hr. Table IV gives the analyses of the nitrate broth before and after the incubation period together with the quantity and the analysis of the gas produced. The nitrates were reduced from 426 to 76 mg/l with an increase in ammonia as nitrogen from 167 to 565 mg/l and a production of 275 ml of nitrogen gas. The source of the nitrogen in the ammonia produced was undoubtedly from the nitrates as well as from the peptones and the beef extract in the nitrate broth.

TABLE IV.—Analyses of Nitrate Broth Inoculated with Zoogleal Organism before and after Incubation for 48 hr.

Item	Before Incubation	After Incubation 48 hr, 30°C
Nitrates (mg/l)	426	76
NH_3 as N_2 (mg/l)	167	565
pH	7.9	8.1
Gas (N_2) produced (ml)	—	275

The four IMVIC tests which were

TABLE V.—Morphological and Biochemical Characteristics of Zoogleal Organisms

Characteristic	Zoogleal Organism	*Zoogloea ramigera*		
	Buck's and Keefer's Studies	Butterfield's Studies (1)	Wattie's Studies (3)	McKinney's and Horwood's Studies (4)
Size of individual rods (μ)	1 by 5	1 by 2 to 4	1.0	0.7 by 1.5
Motile	No	Yes	Yes	Yes
Capsulated	Not demonstrated*	Yes	Yes	Yes
Reaction on sugars	No cleavage	No cleavage	Slight acidity	No cleavage
Growth in aerated versus unaerated media	20 per cent better growth in aerated media	Better growth in aerated media	No difference	Not given
NO_3 reduced to NO_2	Yes	Not reduced	Not reduced	Yes
NH_3 produced from peptones	pH increased to 8.4, probably NH_3	Yes	Not reported	Not reported
Growth in citrate	None	Not reported	Yes	Not reported
Increase in pH	7.2 to 8.4	7.0 to 8.4 to 8.8	6.5 to 7.5	Not reported
Temperature for growth (°C):				
Optimum	30	30	Not reported	Not reported
Minimum	5	4	—	—
Maximum	45	—	—	—

* See Figure 2.

negative, indicate that the organism was not in the coliform group. Urease and catalase were produced but hydrogen sulfide was not. When litmus milk was inoculated, there was no putrefaction, coagulation occurred after 19 days, and the medium became quite alkaline, which indicated that ammonia was produced. No gas was produced in the milk during a 20-day period.

The differences between the morphological, biochemical, and physiological characteristics of the foregoing zoogleal forming organism and *Zoogloea ramigera* as reported by Butterfield (1), Wattie (3), and McKinney and Horwood (4) are indicated in Table V. The organism differed from *Zoogloea ramigera* in that it is non-motile, is not capsulated, and is a diplobacillus with pointed ends. In older cultures chains of six bacilli are formed. The organism reduced nitrates to ammonia. This observation agrees with the studies of McKinney and Horwood but does not agree with results obtained by Butterfield or Wattie.

BOD Reduction with Zooglea Organism

Tests were made to determine how effective the organism was in reducing the 5-day BOD of settled sewage. Several samples of primary settling tank effluent were collected on different days at the Back River plant. Each sample was divided into two portions and put into a 1-gal bottle. To one of these portions which contained 2,700 ml and served as a control, 300 ml of fresh activated sludge was added. To the other portion of sewage which contained 3,000 ml, 50 to 100 ml of a suspension of organisms in Tyrod's broth was added. The two bottles, which were kept at a temperature of 30°C, were aerated for 4 hr and then settled for 30 min. The analyses of the sewage before and after treatment with the activated sludge and with the zoogleal organisms are given in Table VI. There was a BOD reduction of from 55.0 to 70.2 per cent, or an average of 64.2 per cent, where activated sludge was added and a reduction of from 46.9 to 81.5 per cent, or an average of 64.3 per cent, where the zoogleal forming organism was added. Within one hour after the organism had been added and aeration had started, the odor produced by the sewage had disappeared. On the other hand the sewage to which activated sludge had been added was still contributing an odor. After aeration was

TABLE VI.—Reduction in 5-Day BOD of Settled Sewage Aerated in Presence of Zoogleal Forming Organism*

Test No.	Control†			Zoogleal Organism Added‡		
	5-Day BOD			5-Day BOD		
	Before Aeration and Settling (mg/l)	After Aeration and Settling (mg/l)	Reduction (per cent)	Before Aeration and Settling (mg/l)	After Aeration and Settling (mg/l)	Reduction (per cent)
1	137	43	68.6	114	43	62.2
2	109	49	55.0	130	24	81.5
3	126	49	61.0	130	46	64.6
4	128	38	70.2	128	68	46.9
Avg	125	44.8	64.2	126	45	64.3

* Using 4 hr of aeration followed by ½ hr of settling.

† 2,700 ml of primary settling tank effluent aerated in presence of 300 ml of activated sludge.

‡ 3,000 ml of primary settling tank effluent aerated in presence of a 50 to 100 ml suspension of zoogleal organism.

discontinued, sludge in the bottles into which the organism was introduced settled out much quicker than the sludge in the bottle into which activated sludge was added. The sludge that collected in the former bottles was a very light gray whereas the sludge collected in the latter bottles was a medium gray, typical of normal activated sludge. The zoogleal organism was as effective as the activated sludge in reducing the BOD of settled sewage and in producing a well clarified supernatant.

Summary

A zoogleal organism was isolated from the activated sludge at the Back River plant. This organism was obtained in pure culture, and its morphological, biochemical, and physiological characteristics were studied. The organism was in many ways different from *Zoogloea ramigera*, which had been isolated from activated sludge by other investigators. The organism was found to reduce nitrates with the production of ammonia and nitrogen gas. As indicated by the use of alcian blue stain, the gelatinous matrix surrounding the cells contained polysaccharides. When settled sewage was inoculated with the organism, aerated for 4 hr, and settled for ½ hr, the reduction in BOD was comparable to that obtained when activated sludge was used.

Acknowledgments

The Back River sewage treatment works is under the general direction of Bernard L. Werner, Director of Public Works, and R. J. Trautman, Principal Engineer. Dr. Abel Wolman is consultant to the Department of Public Works. Paul L. Smith is superintendent of the plant.

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UTILIZATION OF NITROGEN-CONTAINING COMPOUNDS FOR THE BIOSYNTHESIS OF PROTEIN IN SECONDARY TREATMENT

By George B. Morgan

Assistant Research Professor, The Earle B. Phelps Laboratory for Sanitary Engineering Research, University of Florida, Gainesville, Fla.

Much work has been done to define metabolic pathways in pure cultures of animals and organisms. Yet, little work has been done to investigate these schemes and the side reactions which occur in mixed cultures containing numerous genera of plants and animals. Activated sludge units, trickling filters, sand filters, and similar secondary sewage treatment units provide mixed populations suitable for study.

The classical metabolic pathway of Embden-Meyerhof includes the enzymes which enter into the oxidation of hexose to pyruvate (1). This scheme presents evidence that most bacterial plant and animal cells first form hexosephosphate which is then oxidized to pyruvate. Pentoses are not included in this scheme. Pentose oxidation has been explained by the Gibbs alternate pathway involving the formation of pentosephosphate from hexosephosphate (1). An end product of both schemes is pyruvate, which enters directly into the Krebs citric-acid cycle.

These pathways, including the citric-acid cycle, produce intermediates that are incorporated into the production and interconversion of amino acids. Compounds such as acetate, pyruvate, glycerate, alpha-ketoglutarate, and ribose-5-phosphate (2) (3) (4) (5) (6) (7) (8) (9) can be combined with an organic nitrogen and sulfur source to sustain healthy growth in such mixed cultures.

Apparatus

Sand Filter

Glass columns were filled with sand from a sand filter treating sewage. This filter was biologically mature. These columns were prepared in advance and fed filtered raw sewage at a hydraulic loading of 150,000 gpd/acre until used.

Activated Sludge Unit

Activated sludge was maintained in the laboratory and was fed by the fill-and-draw method. Settled sewage, the principal food, was fortified with powdered skim milk and liver extract so that the solution exerted a BOD of 400 ± 50 mg/l. This nutrient maintained an active sludge with a sludge volume index of 125 (sludge density index of 0.8).

Counting Apparatus

Nuclear-Chicago Corporation counting equipment was used. This consisted of a Model D-47 proportional counter in series with a 192-ultrascaler, C110-B automatic sample changer, D-47 preamplifier, and a C111-B printing timer. Matheson PR gas was used in the proportional counter.

Chromatographic Equipment

Chromatograms were carried out in tall form battery jars. These jars contained glass spirals for paper support and accommodated 14-in. square, two-dimensional chromatograms.

Special Reagents

Carbon-14 labeled compounds used were as follows: Alanine-C^{14}, Urea-C^{14}, L-Valine-C^{14} uniformly labeled, L-Serine-C^{14} uniformly labeled, L-Lysine-C^{14} uniformly labeled, L-Threonine-C^{14} uniformly labeled, Pyruvic-1-C^{14} acid, Pyruvic-2-C^{14} acid, and Pyruvic-3-C^{14} acid.

Methods

Separation of Biological Growth from Sand

The sand was removed from the sand filter columns and mixed with isotonic saline solution. The mixture was rapid-mixed for five minutes and the resulting suspension decanted. This process was repeated four times to complete the removal of the biological material from the sand.

Extraction of Proteins from Suspension

A suspension was cooled to 2°C and rapid-mixed at this temperature for 20 min. The resulting emulsion was rapidly frozen and thawed using dry ice and acetone. This process was repeated three times. Glycerine was added so that the final concentration was 15 per cent and the freezing and thawing was repeated 5 more times.

Sand and other foreign matter were removed from the emulsion by filtration and the filtrate was dialyzed in running distilled water for 24-hr at 4°C. The dialyzing tube was hung in a refrigerator in front of a circulating fan for 12 hr to effect pervaporation. This reduced the volume by 80 per cent.

The proteins were then precipitated from the dialyzed solution by the addition of phosphotungstic acid. The mixture was centrifuged to concentrate the proteins.

Protein Hydrolysis

The precipitated proteins were transferred to a heavy pyrex test tube and diluted to 25 ml with distilled water. To this suspension was added 25 ml of 12 N HCl. The top of the test tube was then sealed in a gas-oxygen flame. This mixture was heated to 97°C and maintained at that temperature for 24 hr, which effectively hydrolyzed the proteins into their individual amino acid components. Cystine was determined by hydrolysis for 4 hr in a 1:1 mixture of 6 N HCl and 90-per cent formic acid.

Amino Acid Analysis

The protein hydrolyzate was dried in a vacuum at 75°C and placed in a desiccator over soda lime for 24 hr to remove excess HCl. The hydrolyzate was dissolved in a minimum amount of distilled water, filtered, and again evaporated to dryness. The final residue was dissolved in exactly 2 ml of 10-per cent 2-propanol, which acted not only as a solvent but also as a preservative and prevented esterification.

The resulting amino acid solution was next applied to chromatographic paper in microliter quantities. Each spot was allowed to dry between applications to keep the surface area as small as possible.

After the amino acid spots were thoroughly dry, the paper was lowered into a chamber containing 6 N ammonium hydroxide. This neutralized the bound and free hydrogen chloride. The amino acids were then hydrated by subjecting the paper containing these spots to steam for 20 min.

The papers were placed in a sealed chamber so that the bottom centimeter of each chromatogram was submerged in a selected solvent. The papers were allowed to develop until the solvent front was within a few centimeters of the top. The chromatograms were dried at 70°C and then sprayed with an acetone solution that contained 0.15-per cent ninhydrin and 5-per cent

acetic acid. The spots were then developed in a dark chamber at 70°C.

The three solvents used for this study were as follows: 1-Propanol: 2-Butanone: Water: Diethylamine 10:10:5:2 (volumetric proportion); 1-Butanol: 2-Butanone: Water: Cyclohexylamine 10:10:5:2 (volumetric proportion), and 2,6-Lutidine: Collidine: Water, 1:1:1 (volumetric proportion); and 1- to 2-per cent diethylamine.

Procedures

Phase I

A one-liter culture of activated sludge was allowed to settle and then washed four times to remove dissolved food substances. It was then aerated for 30 min to utilize most of the absorbed food, thereby assuring the endogenous respirative state.

To this culture was added 50 ml of 0.01-per cent glycine solution containing 10 μc of uniformly labeled glycine-C^{14}. The activated sludge was separated from the supernatant after a five-hour contact period. These two fractions were analyzed for amino acids and each of the following amino acids was analyzed for radioactivity: alanine, arginine, aspartic acid, cystine, glutamic acid, glycine, histidine, leucine, lysine, methionine, proline, serine, valine, phenylalanine, threonine, tyrosine, and tryptophan. Carbon-14 activity in each 100 mg of sludge was as follows: 64 $\mu\mu c$ of glycine, 3 $\mu\mu c$ of serine, 8 $\mu\mu c$ of valine, and 9 $\mu\mu c$ of leucine. Carbon-14 activity in each 100 mg of supernatant residue was as follows: 9.1×10^6 $\mu\mu c$ of glycine and 2.9×10^4 $\mu\mu c$ of serine.

The glycine nutrient from above was used in parallel studies on biologically mature sand beds. The effluent which passed through the filter exhibited a distribution of C^{14} between glycine and serine similar to that in activated sludge. The organisms extracted from the sand exhibited a C^{14} distribution similar to activated sludge except that 11 $\mu\mu c$ of threonine per 100 mg of dried organisms were also present.

This experiment was repeated using 0.01-per cent glycine with 450 $\mu\mu c$ of uniformly labeled sodium pyruvate-C^{14} added, and results showed the formation of glycine and serine. Some radioactivity was also found in threonine and alanine.

The addition of 0.01-per cent glycine to both activated sludge and sand filter with the subsequent addition of $C^{14}O_2$ produced no radioactive amino acids.

Phase II

In this phase the same cultures were used but the nutrient solution was changed. Enough glucose was added to the glycine solution to make its concentration 0.01 per cent, also. These cultures were analyzed as before. Results are shown in Table I.

This experiment was repeated using 5 μc of glycine-1-C^{14} instead of the glycine-C^{14} uniformly labeled. The amino acids derived from these proteins contained less than half as much

TABLE I.—Carbon-14 Activity in Sand Filter and Activated Sludge*

Amino Acid Analyzed	Activated Sludge ($\mu\mu c$/100 mg)		Sand Filter ($\mu\mu c$/100 mg)	
	Sludge	Supernatant	Biological Growth	Supernatant
Alanine	26×10^5	7.14×10^5	31×10^3	11
Arginine	24×10^5	—	61×10^3	—
Aspartic acid	94×10^5	—	84×10^3	—
Cystine	6×10^5	—	41×10^3	—
Glutamic acid	70×10^5	—	112×10^3	—
Glycine	38×10^5	77×10^5	49×10^3	63×10^5
Histidine	20×10^5	—	37×10^3	—
Leucine	20×10^5	6×10^5	91×10^3	37
Lysine	62×10^5	—	55×10^3	—
Methionine	61×10^5	3×10^5	60×10^3	—
Phenylalanine	19×10^5	—	40×10^3	—
Proline	9×10^5	—	14×10^3	—
Serine	9.9×10^5	47×10^5	13×10^4	6×10^5
Threonine	6.9×10^5	6×10^5	51×10^3	—
Tyrosine	39×10^5	—	40×10^3	—
Tryptophan	6×10^5	—	16×10^3	—
Valine	60×10^5	11×10^5	79×10^3	—

* Nutrient solution contained 0.01-per cent glucose and 0.01-per cent glycine and 10 μc glycine-C^{14} uniformly labeled.

TABLE II.—Carbon-14 Activity in Sand Filter and Activated Sludge*

Amino Acid Analyzed	Activated Sludge (μμc/100 mg)		Sand Filter (μμc/100 mg)	
	Sludge	Supernatant	Biological Growth	Supernatant
Alanine	1.4×10^{5}	3×10^{3}	2.6×10^{5}	4.0×10^{1}
Arginine	6×10^{4}	—	3×10^{4}	—
Aspartic acid	9×10^{4}	—	11×10^{4}	1.1×10^{1}
Cystine	41×10^{3}	—	6.1×10^{5}	—
Glutamic acid	1.7×10^{5}	4×10^{3}	1.5×10^{5}	7.3×10^{3}
Glycine	6.5×10^{5}	8.3×10^{3}	7.8×10^{5}	6.4×10^{3}
Histidine	3.7×10^{4}	—	2.9×10^{3}	—
Leucine	1.9×10^{5}	6.4×10^{1}	2.8×10^{5}	5.2×10^{2}
Lysine	3.7×10^{4}	1.9×10^{3}	5.7×10^{4}	4.3×10^{3}
Methionine	4.1×10^{4}	—	8.1×10^{4}	—
Phenylalanine	17×10^{3}	—	2.6×10^{4}	—
Proline	6×10^{3}	—	9.5×10^{3}	—
Serine	1.1×10^{5}	6.7×10^{3}	9.8×10^{4}	6.1×10^{3}
Threonine	7.6×10^{4}	9.2×10^{1}	7.7×10^{4}	7.5×10^{2}
Tryptophan	1.1×10^{3}	—	1.7×10^{3}	—
Tyrosine	16×10^{3}	—	1.8×10^{3}	—
Valine	8.8×10^{5}	6.3×10^{3}	7.5×10^{5}	9.3×10^{3}

* Nutrient solution contained 0.01-per cent glycine and 0.01-per cent glucose and 10 μc D-glucose-C^{14} uniformly labeled.

activity as those derived from the uniformly labeled glycine.

Phase III

Again, similar cultures were used but the nutrient changed. This nutrient solution consisted of 0.01-per cent glycine, 0.01-per cent glucose, and 10 μc D-glucose-C^{14} uniformly labeled. Results found after a five-hour contact period are shown in Table II.

TABLE III.—Composition of Nutrient Solutions Used in Phase IV Studies (g/100 ml)*

Solution No.	Glucose	Other
1	0.1	Glycine: 0.1
2	0.1	Valine: 0.1
3	0.1	Serine: 0.1
4	0.1	L-Threonine: 0.1
5	0.1	L-Lysine: 0.1
6	0.1	Alanine: 0.1
7	0.1	Urea: 0.1

* Each solution contained 1 μc/100 ml of glucose C^{14} uniformly labeled.

Phase IV

Seven sand filter columns were constructed and columns 1–7 were fed nutrient solutions 1–7, respectively. The composition of these nutrient solutions is shown in Table III.

The biological growth was removed after five hours and analyzed in the usual manner. Results in Table IV show a comparison of the labeled amino

TABLE IV.—Carbon-14 Activity in the Biological Growth of Sand Filter Columns*

Material Analyzed	Activity in Column (μμc/100 g)						
	1	2	3	4	5	6	7
Alanine	1.7×10^{3}	990	1.4×10^{4}	1.2×10^{3}	1.1×10^{3}	1.5×10^{3}	2.1×10^{4}
Arginine	2.5×10^{2}	68	9.9×10^{2}	220	140	2.7×10^{2}	1.3×10^{3}
Aspartic acid	1.4×10^{3}	702	1.4×10^{3}	472	672	1.4×10^{3}	1.5×10^{3}
Cystine	229	139	2.6×10^{2}	46	127	221	400
Glutamic acid	3.7×10^{3}	112	6.1×10^{3}	320	820	3.6×10^{3}	8.5×10^{3}
Glycine	2.6×10^{4}	3.9×10^{3}	2.2×10^{4}	1.2×10^{3}	8.6×10^{3}	2.1×10^{4}	2.5×10^{4}
Histidine	2.8×10^{3}	99	4.7×10^{3}	42	1.2×10^{2}	2.9×10^{3}	5.2×10^{3}
Leucine	8.1×10^{3}	288	2.0×10^{4}	170	5.0×10^{2}	7.7×10^{3}	2.2×10^{4}
Lysine	1.5×10^{3}	429	1.9×10^{3}	742	1.0×10^{3}	1.4×10^{4}	2.1×10^{4}
Methionine	8.2×10^{3}	216	1.8×10^{3}	162	4.4×10^{2}	9.6×10^{3}	2.2×10^{4}
Phenylalanine	8.5×10^{3}	140	1.4×10^{3}	72	2.1×10^{2}	8.4×10^{3}	1.7×10^{3}
Proline	1.4×10^{2}	79	2.2×10^{3}	46	1.3×10^{2}	1.6×10^{2}	2.7×10^{3}
Serine	1.3×10^{4}	1.7×10^{3}	2.4×10^{3}	842	6.9×10^{3}	1.4×10^{4}	2.7×10^{4}
Threonine	7.9×10^{3}	265	1.4×10^{4}	102	3.2×10^{2}	8.7×10^{3}	1.7×10^{4}
Tryptophan	27	11	62	5	7	16	100
Tyrosine	32	27	69	11	19	36	97
Valine	1.5×10^{4}	4.7×10^{3}	2.5×10^{4}	1.0×10^{3}	8.4×10^{3}	1.3×10^{4}	2.9×10^{4}
Unhydrolyzed sludge	1.6×10^{5}	5.6×10^{4}	1.7×10^{5}	1.1×10^{4}	7×10^{3}	1.1×10^{5}	2.4×10^{5}

* Nutrient solution composition given in Table III.

acids produced from each nutrient solution.

Phase V

Three sand filter columns were fed with nutrient solution 7 (Table III). Enough potassium cyanide to make a 0.01 N solution was added to the solution for Column 1 and an equivalent amount of iodoacetic acid was added to the solution for Column 2. Column 3 was the control.

Again, the growth was analyzed in the usual manner after a five-hour contact period. Columns 1 and 2 showed practically no synthesis of labeled amino acids while Column 3 produced the usual spectrum.

This experiment was repeated using Solution 1 (Table III). Columns 1 and 3 exhibited the same results as Columns 1 and 3 above, but Column 2 contained 843 $\mu\mu$c of serine per 100 mg of sludge.

Results

The utilization of glycine appears to be negligible unless there is some source of energy. The production of serine from glycine is probably due to extracellular enzymes. Although the lengthening of glycine to serine is a simple addition, the carbon evidently cannot come from CO_2. Pyruvic acid is probably one of the ready donors.

The addition of sufficient carbohydrate causes the synthesis of proteins to increase greatly. Glycine has been shown to enter into the general production of amino acids and results from Phase II indicate that both carbon atoms are utilized probably by the conversion of glycine to acetic acid via glycolic aldehyde. It is obvious from this point that glycine has entered the citric acid cycle, probably by acetate-oxaloacetate combination. Further evidence of this entry is the evolution of $C^{14}O_2$ from the culture.

Of the seven organic nitrogen sources used, urea appears to be utilized with the greatest facility. Glycine and serine also seem to be good nitrogen sources. Results from these two amino acids varied only slightly because of the glycine-serine interconversion. The nitrogen sources not only donate an NH_2 group but form pyruvic acid, a precursor of several amino acids. Glycine, alanine, and serine can be converted directly from pyruvic acid; valine is produced from pyruvate via ketoisovalerate, while leucine has ketocaproate as an intermediate. Threonine, the precursor of aspartic acid, can be formed by a reversal of the well-known cleavage of threonine to glycine, while glutamic acid is known to evolve from alpha-ketoglutarate. The carbon for sulfur-containing amino acids probably arises from pyruvate and glutamate combination.

The addition of iodoacetic acid or potassium cyanide prevented the formation of labeled amino acids from labeled glucose. The dehydrogenase system was blocked, which prevented the oxidation of glucose beyond 1, 3-glyceraldehyde diphosphate, hence the interruption of the Embden-Meyerhof or Gibbs pathway.

Summary

Synthesis of proteins in activated sludge units and sand filters treating sewage is integrated with the well-known Gibbs and Embden-Meyerhof pathways. Urea appears to be a better NH_2 donor than even the simplest amino acids. Most of the amino acids added to these units were oxidized in the citric acid cycle. Some of the components of this cycle were then used to produce other amino acids that were incorporated into protein synthesis.

Acknowledgment

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AN APPLICATION OF THE PRINCIPLES OF BIOLOGICAL ENGINEERING TO ACTIVATED SLUDGE TREATMENT *

By H. R. Zablatzky, M. S. Cornish, and J. K. Adams

Chief Operator, Chemist, and Superintendent, Bergen County Sewer Authority, Little Ferry, N. J.

The Bergen County Sewer Authority is currently planning a major extension of its collection system which will serve 15 additional municipalities in Bergen County, New Jersey. The anticipated increase in flow, approximately equal to the present flow, will necessitate additions to the existing treatment facilities at Little Ferry. Consideration has been given to the introduction of high-rate biological treatment in order to keep construction costs to a minimum.

Plant Description

The plant as designed is a 20-mgd activated sludge plant employing separate sludge digestion. Six aeration units, each having a capacity of slightly over 1 mil gal follow the primary settling tanks. Each aeration tank is of the single-pass type and 300 ft long; with step ports 6-, 103-, and 200-ft from the influent end of the tank. Each tank is a separate unit except for an air header common to each pair of tanks. The aeration units are followed by four rectangular settling tanks. Figure 1 shows the plant layout.

In order to utilize a high-rate process and achieve a high removal of BOD and suspended solids, it is necessary to limit the time during which the microorganisms responsible for purification are in contact with the substrate.

According to Phelps (1) and others (2), the rapid clarification of sewage by activated sludge is possible if some type of reactivation is utilized. A study of the works of some of the leading investigators in the field of sewage and industrial wastes suggested the possibility that the present process

* Presented at the 43rd Annual Meeting, New Jersey Sewage and Industrial Wastes Assn.; Atlantic City, N. J.; Mar. 12–14, 1958.

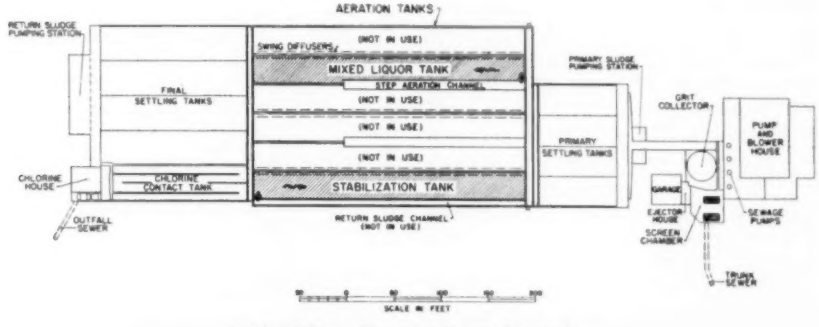

FIGURE 1.—Layout of aeration tanks.

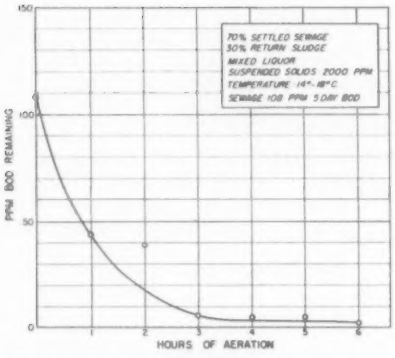

FIGURE 2.—Influence of aeration time on BOD.

might be converted to a high-rate process with a minimum of equipment alteration or replacement.

Laboratory Development of the Process

To determine the amount of BOD which can be removed with respect to time, a mixed liquor of primary effluent and return sludge was prepared and aerated. The BOD of the supernatant was determined at the intervals shown in Figure 2. It is readily observed that suitable BOD reduction can be effected after a short contact period.

Oxygen requirements and the time required for sludge stabilization had to be determined. This was done by recording the oxygen uptake and plotting it against aeration time as shown in Figure 3. It is believed that oxygen requirements for biological aeration systems can be developed from experiments of this nature. Eckenfelder's (3) concepts were used to compute required air rates, and a value of 5 per cent was used for the oxygen transfer efficiency.

The proportion of directly oxidizable BOD was derived from the curve shown in Figure 4 as were the oxygen requirements for the synthesis of BOD to bacterial cells. The degree of oxygen utilization for endogenous respiration of the microorganisms can also be derived from this curve (4).

Hoover and Porges (5) define endogenous respiration as the oxidation of the microorganisms' own tissue for energy. It is analogous to basal metabolism in humans. From the literature (5)(6)(7), it appears that the oxygen requirements of an activated sludge process are based chiefly on: (a) the oxygen needed for microbial respiration; and (b) the oxygen needed for oxidizing and synthesizing BOD to more stable compounds. Because of the synthesis of the BOD into cellular structure, it would appear to be erroneous to base aeration operation

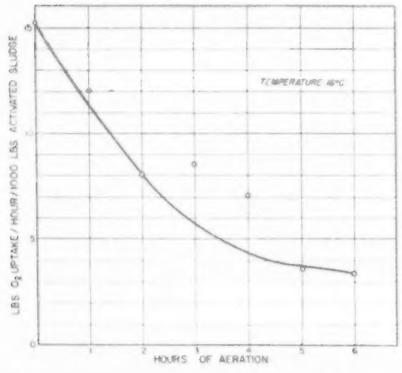

FIGURE 3.—Influence of aeration time on oxygen uptake.

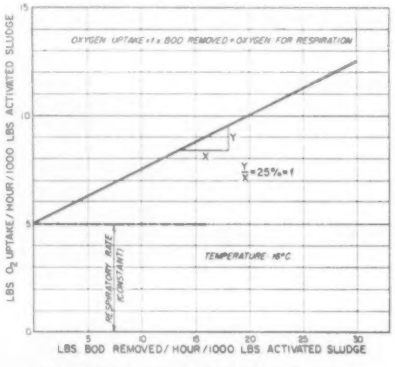
OXYGEN UPTAKE = f x BOD REMOVED + OXYGEN FOR RESPIRATION
Y
X
Y/X = 25% = f
TEMPERATURE 16°C
RESPIRATORY RATE CONSTANT
LBS O2 UPTAKE / HOUR / 1000 LBS ACTIVATED SLUDGE
LBS BOD REMOVED / HOUR / 1000 LBS ACTIVATED SLUDGE

FIGURE 4.—Relationship of oxygen uptake to BOD removal.

on balancing incoming suspended solids with the weight of excess sludge.

BOD can be in a liquid or solid form. Removal of BOD in the liquid form may require a longer contact with the mixed liquor or a greater "sludge" concentration than does the BOD in the colloidal form. The BOD in this latter form may be removed quickly from the surrounding solution by the zoogleal masses moving through the solution like a lace filter. Once these solids have adhered to the matrix, however, stabilization may take longer than that necessary for stabilization of liquid-form BOD. Note that a distinction was made between mixed-liquor time and sludge stabilization time.

The theoretical maximum load which can be applied to the process at any one time can be computed by using the formulations of Eckenfelder and O'Connor (7), and Haseltine (8) has shown that a definite relationship exists between BOD loads and solids under aeration. Figure 5 shows the relationship between the fraction of BOD removed and the weight of BOD applied per pound of sludge under aeration. McKinney *et al.* (9) point out the value of food, solids, and time relationships in the activated sludge process.

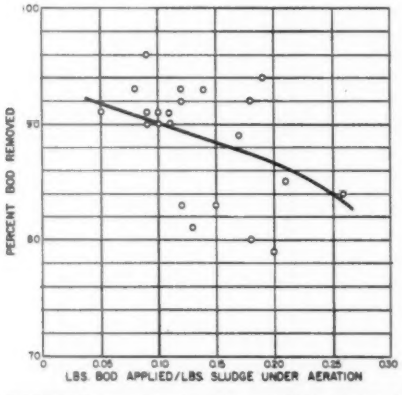

FIGURE 5.—Relationship of BOD applied to BOD removed.

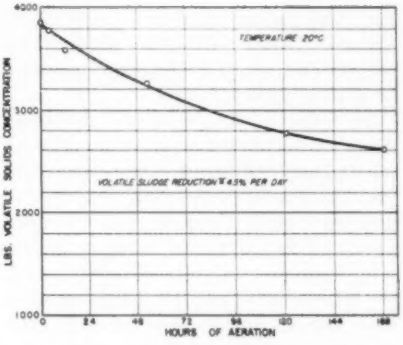

FIGURE 6.—Influence of aeration time on volatile solids reduction.

Considering the relationships already described, it seemed possible to establish a "contact-stabilization" process. Final laboratory work was undertaken to establish a self-digestion rate for the microorganisms. The results of this investigation are illustrated in Figure 6.

All dissolved oxygen measurements were made with a polarograph using a dropping-mercury electrode (10). Dissolved oxygen uptakes were also determined with the polarograph (11).

Plant-Scale Application of Data

The laboratory results appeared promising. However, it was decided that the mixed-liquor time should be reduced gradually to allow for the difference between laboratory and plant-scale operation.

A stabilization period with a sufficient quantity of dissolved oxygen was needed. Fortunately, the original plant design made it possible to use the first aeration tank for this purpose. Aerators 2, 3, 4, and 5 were used as mixed-liquor tanks and a gradual reduction of mixed-liquor time was started. The reduction continued with excellent results until only one mixed-liquor tank and one stabilization tank were in service. Process efficiency dropped at this time. Investigation of this decline showed that insufficient

air was being supplied at various points. After diffusers were thoroughly cleaned, the efficiency increased to a satisfactory range.

In order to determine the detention times at which the process would fail, all primary effluent was discharged at the 200-ft inlet port. This allowed one and two-thirds aerators for stabilization and one-third of an aerator for mixed liquor. After a short period of satisfactory results, one stabilizer tank was removed from service leaving only one-third of an aerator for mixed liquor and two-thirds of an aerator for stabilization. A month passed and the performance began to decline and air pressures began to build up to abnormal levels. The BOD applied during this period was at an average rate of 98.1 lb/1,000 cu ft of total aeration tank capacity or 294.3 lb/1,000 cu ft of mixed-liquor capacity. The mixed liquor detention time was 0.36 hr with a stabilization time of 2.23 hr. In reviewing the degradation, it appeared that the load factors were out of balance. This was caused by the inability of the original design to provide sufficient air to support the high rate of oxygen utilization under the greater microbial concentrations and BOD loads per unit volume. Air diffusers appeared to be externally clogged by biological slimes. It should be stated that air rates exceeded the equipment manufacturer's recommendation. This failure spawned the thought that other types of oxygen-dispersion units might be more suitable for this type of treatment.

Upon returning the system to a one-stabilizer-tank-and-one-mixed-liquor-tank operation, the efficiency of the

TABLE I.—Plant Operation Data

Date	Air Use (cu ft/lb of BOD removed)	Mixed Liquor Aeration (hr)	Sludge Stabilization Period (hr)	BOD Loading (lb/day/1,000 cu ft of mixed liquor)	BOD Loading (lb/day/1,000 cu ft of aeration capacity)	BOD Removal (%)
Jan. 1956*	918	.44	2.76	324.0	111.9	91.5
Feb. 1956*	970	.85	2.30	136.3	112.7	80.5
Mar. 1956*	1,083	.72	2.07	159.0	106.4	81.7
Apr. 1956	1,344	1.03	4.68	90.4	45.2	79.0
May 1956	1,305	1.20	3.49	79.3	39.7	88.0
June 1956	1,629	1.47	5.39	73.2	36.6	80.0
July 1956	1,560	1.56	5.51	68.6	34.3	88.0
Aug. 1956	1,307	1.59	5.16	79.8	39.9	91.0
Sept. 1956	1,462	1.55	5.06	71.9	35.9	90.0
Oct. 1956	839	1.68	5.06	89.9	49.9	89.2
Nov. 1956	1,429	1.47	4.43	75.0	37.5	89.5
Dec. 1956	1,177	1.38	5.06	88.1	44.1	92.5
Jan. 1957	940	1.42	4.97	114.9	57.5	79.0
Feb. 1957	1,100	1.09	2.82	94.7	47.4	80.0
Mar. 1957	1,095	1.12	3.76	101.6	50.8	83.0
Apr. 1957	1,225	.96	3.54	99.0	49.5	86.0
May 1957	1,390	1.24	4.52	87.3	43.7	91.0
June 1957	1,930	1.36	4.43	77.6	38.8	93.0
July 1957	1,280	1.50	4.68	71.4	35.7	97.0
Aug. 1957	1,560	1.52	4.14	57.9	29.0	94.7
Sept. 1957	1,030	1.42	3.82	79.0	39.5	94.0
Oct. 1957	1,185	1.41	3.60	80.3	40.2	95.0
Nov. 1957	1,160	1.34	3.36	82.9	41.5	94.4
Dec. 1957	946	1.02	3.14	98.0	49.0	93.9

* In months denoted by asterisk, aeration was carried on in one tank; ⅔ of tank for stabilization and ⅓ for mixed liquor. In all other months one tank was used for stabilization and one for mixed liquor.

system again began to improve. Sludge bulking, at all times, was held to a minimum, but floating solids in the final settling tanks caused occasional problems. Provision of skimming devices in these tanks would undoubtedly overcome this difficulty.

The results for another run in the first quarter of 1956 using one-third of an aerator for mixed liquor and two-thirds of an aerator for stabilization are tabulated in Table I. Almost identical problems were encountered in regard to air difficulties.

Table I also lists plant results obtained over a 21-month period during which the contact-stabilization process was employed by using two tanks, one for stabilization and one for mixed liquor.

It should be noted here that the air-supply per pound of BOD removed may appear to be somewhat high. This indication of excessive air use can be explained by (a) the inability of the diesel-driven air compressors to deliver air in small enough quantities during periods of low oxygen demand, (b) the loss of air through leakage in the underground piping system, and (c) the use of air for other purposes.

To establish the distribution of the oxygen-consuming load in the aeration system, Figure 7 was developed from tests made during actual operation.

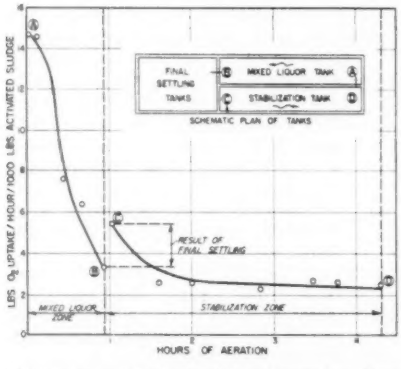

FIGURE 7.—Relationship of aeration time to oxygen uptake.

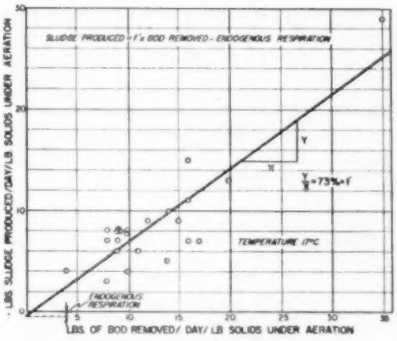
SLUDGE PRODUCED = f's BOD REMOVED - ENDOGENOUS RESPIRATION
Y
X
$\frac{Y}{X}$ = 73%= f
TEMPERATURE 17°C
ENDOGENOUS RESPIRATION
LBS SLUDGE PRODUCED/DAY/LB SOLIDS UNDER AERATION
LBS. OF BOD REMOVED/ DAY/ LB SOLIDS UNDER AERATION

FIGURE 8.—Relationship of sludge production to BOD removal.

The stability of the sludge at any point in the system may be ascertained by means of this graph.

In an attempt to confirm experimental concepts (Figure 4) with respect to plant operation, Figure 8 was developed from the operating data. This plot shows the order of magnitude for the fraction of BOD that is synthesizable and includes an approximate figure for the endogenous respiration rate (4). The *f'* factor of 73 per cent as derived from the curve in Figure 8 plus the *f* factor of 25 per cent as derived from Figure 4 should theoretically total 100 (4). The results are unusually close considering the errors that are possible in correlating theory, laboratory data, and plant operational data. Others in the waste field have also derived sludge growth constants (5)(7)(12)(13).

Figure 9 shows typical ammonia, nitrite, and nitrate curves which give an indication of the stage of the oxidation process during various phases of aeration.

It is of interest to report that prior to adopting the operating procedures described herein, frothing in the aeration tanks had created costly operating problems. Once the contact-stabilization process had been established, frothing ceased to be a problem. In this respect, Hood's (14, 15) explanation of the causes of frothing, which

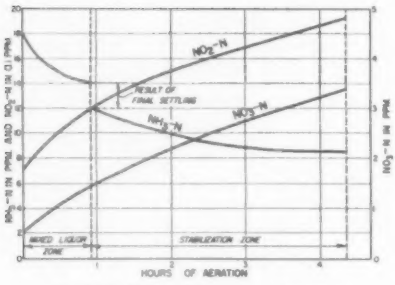

FIGURE 9.—Nitrogen changes during aeration.

attributes frothing largely to the specific stages of oxidation in a system, is brought to mind.

Summary and Conclusions

1. The contact-stabilization method of activated sludge treatment appears to offer a satisfactory and economical solution to the problem of providing future plant facilities by the Bergen County Sewer Authority.

2. Oxygen requirements, stabilization time, mixed-liquor contact time, and load factors were obtained from experiments. Based on the factors thus derived, plant operation of the process was begun and continued over a period of two years. Detention times for sludge stabilization and mixed-liquor contact were varied to establish failure levels and peak efficiencies.

3. The efficacy of the process is largely dependent on the effectiveness of the stabilization process, temperature of the sewage, and uniformity of incoming BOD and suspended solids. High efficiency has been obtained by its utilization. Shock loads of industrial wastes have had little, or only brief, effect on the process. The exception to this was one failure where BOD removals dropped to about 70 per cent. This degradation occurred during a prolonged period of heavy industrial-waste loading when winter temperatures ranged from 7 to 10°C.

4. Frothing, which developed under standard aeration and required application of defoaming agents for control, was reduced to negligible amounts under the contact-stabilization process.

5. Based on an average flow of 14 mgd over the period during which the process was employed, it appears that the present aeration tank capacities are sufficient to treat at least 56 mgd, or twice what would normally be considered adequate under standard aeration. With improved dispersion units and sufficient air supply it is likely that even larger flows may be treated efficiently with the existing units.

Acknowledgments

The authors appreciate the help and cooperation of all their co-workers in the establishment of this process.

The work described could not have been done without the knowledge and approval of the Commissioners of the Bergen County Sewer Authority and the Clinton Bogert Engineers.

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UNITED ENGINEERING CENTER

Ground was broken October 1 for the 18-story United Engineering Center at United Nations Plaza in New York. Herbert Hoover, representing 300,000 members of 18 major engineering societies, was assisted by a young engineering student from Hawaii in the ground breaking ceremonies.

The United Engineering Center, scheduled for completion in mid-1961, will house the headquarters of major engineering societies and joint engineering groups. It has been made possible by contributions from industry and from thousands of individual engineers. Plans for the Center have been eight years in the making. To date, more than 500 companies have contributed nearly $5 million, and some 56,000 engineers have added another $3 million.

The Center, which will house about 600 staff members of the engineering groups, is located at First Avenue between 47th and 48th Streets and will be part of a complex of new buildings located on United Nations Plaza.

Work on the Center was scheduled to begin October 15.

Industrial Wastes

DESIGN DATA FOR BIOLOGICAL TREATMENT OF COMBINED WASTES *

By Thomas P. Quirk

Malcolm Pirnie Engineers, New York, N. Y.

The design of waste disposal plants receiving domestic and industrial discharges invariably requires special consideration of the treatment process selected, the type of process equipment required, and the particular operational problems associated with the combined wastes. When the design of these treatment systems envisions the use of aerobic biological treatment, the functional requirements of certain industrial effluents become even more vital to the proper operation of the system.

The nature of aerobic biological systems is such that the stability and continued operation of the process is dependent on maintaining a state of dynamic equilibrium among a large number of variables, many of which are not subject to the direct control of the system operator. It is this tenuous balance which requires investigation in the light of the characteristics of the industrial discharges expected. It is not uncommon for combined industrial and domestic effluents to require waste treatment systems of such a size and nature that their cost becomes prohibitive.

By the same token, however, the presence of certain industrial wastes may give properties to the composite discharge which allow the required treatment units to be significantly reduced in size when compared to the standards applicable to normal domestic sewage. In addition, the combined waste may exhibit characteristics which materially enhance the operation of the entire system.

It is generally advisable, then, to conduct specific pilot-type investigations when the lack of operational experience with the particular waste leaves many of these questions unanswered. Full pilot-plant investigations, while providing the most reliable form of operational data, can be costly as well as time-consuming. In many instances laboratory-scale studies can provide valuable information concerning process feasibility, system operation, and stability. The knowledge gained from these studies may justify the limiting of pilot-plant investigations, if they are required, to specific areas.

It is the purpose of this paper to present the results of a laboratory-scale study conducted to determine the feasibility of employing the activated sludge process to a mixture of domestic sewage and several industrial effluents. Treatment studies were conducted to evaluate oxygen transfer properties, process loading-removal characteristics, oxygen demand rates, required detention times, and sludge handling characteristics.

Waste Characteristics

The principal waste streams considered for secondary treatment consisted

* Presented at the 13th Purdue Industrial Waste Conf., Purdue University; Lafayette, Ind.; May 5–7, 1958.

of a mixture of domestic sewage and the effluents from two large cereal factories and separate discharges from two board mills. The wastes discharged from the cereal industries were composed of highly carbonaceous material and contained maltose and related sugars from spent flavor solutions, grain losses, cereal nutrients, vitamin additives, and general process drag-out. As a result of 24-hr plant operation, the waste loadings contributed by the cereal industries were of relatively constant intensity. The clean-up loads were not of sufficient magnitude to warrant special consideration.

The board mills produced bleached and colored folding carton board from several raw materials, including various grades of waste paper, newsprint, and kraft board. Digestion and raw pulp preparation through chemical treatment of wood fiber were not practiced at the mills. The wastes discharged contained dissolved and suspended material from the pulping operations as well as various chemicals from the bleaching, brightening, and coloring of the raw pulp, and spent waters from the board machines. Twenty-four-hour mill operation resulted in essentially stable waste loadings. Clean-up discharges were equivalent to about one-half day of normal operation.

A summary of the pertinent characteristics of the wastes is shown in Table I. The source of the wastes, the high values of the BOD velocity constant K_1, the significant proportions of the BOD in dissolved form, and the comparatively high BOD to nitrogen ratios indicated that biological treatment of a combination of the wastes might require special consideration of process feasibility, operative loading levels, oxygen supply rates, and sludge handling characteristics.

TABLE I.—Average Characteristics of Waste Components

Characteristic	Mixture of Sewage and Cereal Effluent	Board Mill Effluent
BOD (mg/l)	327	173
K_1 (per day)*	0.32	0.17
BOD dissolved (per cent)	50	70
Suspended solids (mg/l)	221	327
Volatile suspended solids (per cent)	86	54
BOD-SS equivalent	0.74	0.15
BOD/Kjeldahl nitrogen	15	35

* Based on common logarithms.

TABLE II.—Average Characteristics of Combined Raw Waste

Characteristic	Amount
BOD (mg/l)	285
K_1 (per day)*	0.28
BOD dissolved (per cent)	53
Suspended solids (mg/l)	255
Volatile suspended solids (per cent)	74
BOD-SS equivalent	0.54
BOD/Kjeldahl nitrogen	18

* Based on common logarithms.

The average characteristics of the combined wastes are shown in Table II. The combined wastes exhibited a moderate total oxygen requirement at a comparatively high rate. The 5-day BOD represented about 96 per cent of the ultimate oxygen requirement for long term stabilization, or about 40 per cent more than normal domestic sewage of the same ultimate BOD. The fraction of BOD in dissolved form was about twice the corresponding value for sewage, while the BOD-suspended solids equivalent averaged only 11 per cent greater than the sewage counterpart (1). The BOD to nitrogen ratio was slightly higher than the value of 17 considered optimum for the aerobic stabilization of domestic and industrial wastes (2).

Experimental Studies

Laboratory apparatus similar in operation to that employed by other investigators (3)(4), was used in the bench-scale treatment study. A build-up of properly acclimated sludge was obtained by seeding a mixture of the

wastes with activated sludge taken from a nearby sewage treatment plant. The mixture of sludge and waste was aerated in a 55-gal drum, using a pair of drilled pipes as diffusers. The air supply was controlled by a valve inserted in the feed line. The initial ratio of waste to sludge was selected at 0.15 lb BOD per pound of sludge, and a feeding interval of 23 hr was employed.

In order to monitor the production of a sludge floc, well acclimated to the new waste, the proportion of feed to sludge was changed periodically to maintain a constant sludge loading. As the feed waste exhibited a fairly constant BOD, control was effected by adjusting either the concentration of mixed liquor sludge retained in the drum or the volume of feed waste added, in proportion to the change in mixed liquor sludge concentration after each aeration period. An increase in net solids concentration was accompanied by a discharge of a corresponding quantity of sludge, prior to the addition of feed waste. A net solids reduction was compensated for by increasing the quantity of feed in proportion to the decrease in solids. When the net solids concentration remained unchanged, the volume of feed was arbitrarily increased. In this manner a complete turnover of sludge under fairly constant loading conditions

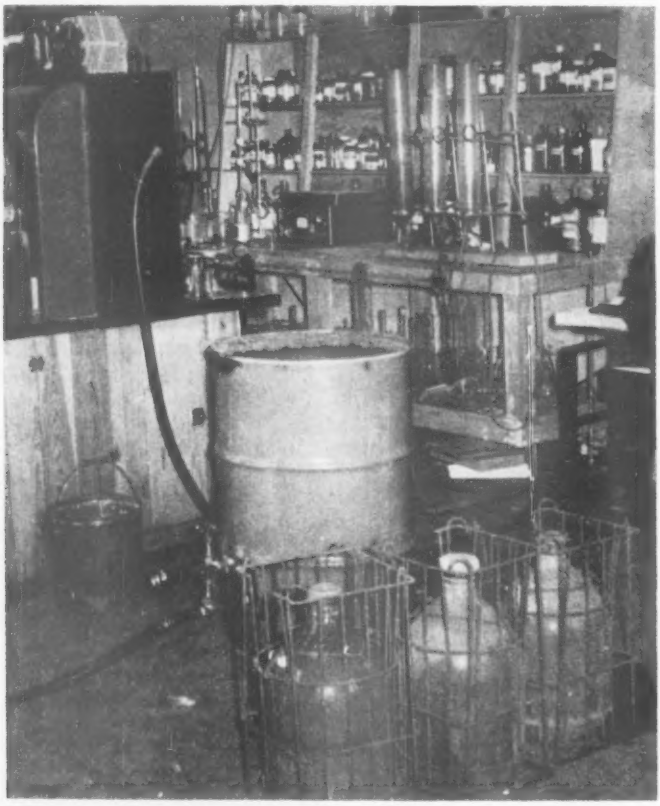

FIGURE 1.—Aeration drum and feed waste containers with 4 liter cylinders in background.

was insured. In order to determine when an acclimatized sludge had been produced, the reduction in supernatant BOD was plotted against time. A constant BOD reduction was taken as indicative of proper acclimation. A constant reduction was obtained after about 7 days of feeding, at which time the feeding interval was decreased to 8 hr, resulting in a loading level of about 0.5 lb BOD per pound of sludge per day of aeration. Throughout the procedure the air supply was adjusted to maintain at least 2 mg/l of dissolved oxygen in the drum liquor.

To simulate various loading conditions, three 4-liter cylinders were used to aerate mixtures of the raw waste. Mixed liquor samples were withdrawn after aeration periods of 30 min, 1, 2, 3, and 4 hr. The samples were allowed to settle for 2 hr prior to determination of supernatant residual BOD. Parallel determinations of the oxygen uptake rate of the aerating mixture were made, employing a polarograph and dropping mercury electrode. A separate polarogram was constructed for the combined waste and an electrode potential of 0.6 v was selected for the study. Suspended and volatile suspended solids determinations were made on the aerating mixture after aeration periods of 30 min and 4 hr. In order to arrive at the approximate concentration of active sludge present in the cylinders, the solids determinations were adjusted for the quantity of inert material present in the feed waste. Sludge volume indexes were taken on the mixed liquor after 4 hr of aeration. Individual 2-liter graduated cylinders were used to simulate the effects of primary sedimentation on BOD removal. Typical arrangements of the equipment are shown in Figure 1.

Primary Sedimentation Performance

The mixture of sewage and cereal wastes received primary treatment at an existing sewage treatment plant. Analyses revealed that a BOD reduction of about 30 per cent was obtained after 1 hr of primary sedimentation. Individual laboratory settling of the board mill wastes resulted in a BOD reduction of about 12 per cent after one hour of quiescent settling. Three-hour sedimentation resulted in a reduction of only 15 per cent. These removals correlated quite closely with the reductions calculated from the suspended solids removal and the measured BOD-solids equivalents.

A mixture of the primary effluent and the presettled board mill effluent was used in the subsequent studies.

Oxygen Transfer Characteristics

Theory and Practice

The rate of transfer of oxygen from the gaseous to the liquid phase is dependent on the degree of undersaturation of the receiving liquid, the amount of interfacial surface provided between the phases, and the combined diffusional resistance of the gaseous and liquid films which are presumed to exist between the phases at the surface of contact (5). For convenience in measurement, the factors of available interfacial area and diffusional resistance have been combined in a single gross transfer coefficient. Under these conditions, the rate of change of oxygen concentration in a given aqueous solution can be expressed as a function of the gross transfer coefficient and the momentary oxygen saturation deficit.

In the aeration of a waste mixture, the selection of a particular type of aeration device and its location within a given aeration tank determines the effect of a number of variables on the rate of oxygen transfer. As the liquor depth over the diffusers remains constant, the increase in oxygen saturation level provided by the increase in oxygen partial pressure at the diffuser outlets exerts a fixed influence on the rate of transfer. The effect of liquor depth on the interfacial film thickness

and consequent diffusional resistance also remains unchanged. Aeration tank geometry defines the tank circulation velocities for a given air and waste flow and thereby limits the exposure time for mass transfer between the gaseous and liquid phases. For practical purposes, the waste temperature and its effect on oxygen saturation is beyond operational control.

The primary determinants of the rate of oxygen transfer within operational control are limited to the degree of undersaturation as defined by the concentration of dissolved oxygen carried in the aerating liquor and the magnitude of the gross transfer coefficient resulting from adjustments of the air flow rate effecting tank turbulence, air bubble formation rate, bubble size, and coalescence rate.

Practical limitations in blower capacity, however, inscribe the limits within which transfer efficiency may be increased through adjustment of the air flow rate. For the typical diffuser in present use, the gross transfer coefficient varies as the $^3/_4$-power of the air rate (6). Accordingly, a 25-per cent reduction in gross transfer characteristic requires a 35-per cent increase in blower delivery to meet a specific oxygen demand while maintaining a given DO concentration in the aerating liquor. In view of these practical limitations on the rate of oxygen transfer and the necessity for designing an aeration system capable of meeting future process requirements, it becomes important to define the effects of the various waste substrates on the transfer properties of the mixed waste. This information is particularly important when specific operational data for the waste considered are unavailable.

As most available data rating aeration systems are based on transfer properties obtained in water, a comparison of the transfer characteristics in the waste with a control solution approximating water permits the selection of an aeration system designed to satisfy process oxygen requirements regardless of the transfer difficulties resulting from low saturation or high diffusional resistance.

Transfer Measurements

In order to evaluate the relative absorption characteristics of the settled waste, the gross oxygen transfer coefficients of the raw and oxidized waste were compared with the transfer coefficient of a control solution of one-per cent potassium chloride. Deaerated samples of each solution were aerated in a 1-liter graduated cylinder using a spherical, porous stone diffuser and an air rate of 25 ml/min. The laboratory air rate was equivalent to a prototype rate of 0.8 cu ft/gal when employing a 4-hr aeration time. The momentary dissolved oxygen concentrations were measured, using a precalibrated polarograph (7), at various time intervals until the solutions approached saturation.

The exponential gross transfer rate was obtained by plotting the variation of the saturation deficit with time on semilog paper and obtaining the slope of the line of best fit. The results are summarized in Table III and graphically illustrated in Figure 2. The data revealed that 4 hr of aeration in the presence of about 2,000 mg/l of activated sludge increased the dissolved oxygen saturation level of the waste from about 90 per cent of the

TABLE III.—Oxygen Transfer Characteristics

Sample	Gross Transfer Coefficient*		DO Saturation	
	Per Hour	Relative	(mg/l)	Relative
1-per cent KCl	8.36	1.00	8.70	1.00
Raw waste	5.90	0.72	7.90	0.91
Oxidized waste†	8.20	0.98	8.69	1.00

* Based on common logarithms.

† Four hours aeration ± 1,900 mg/l mixed liquor suspended solids.

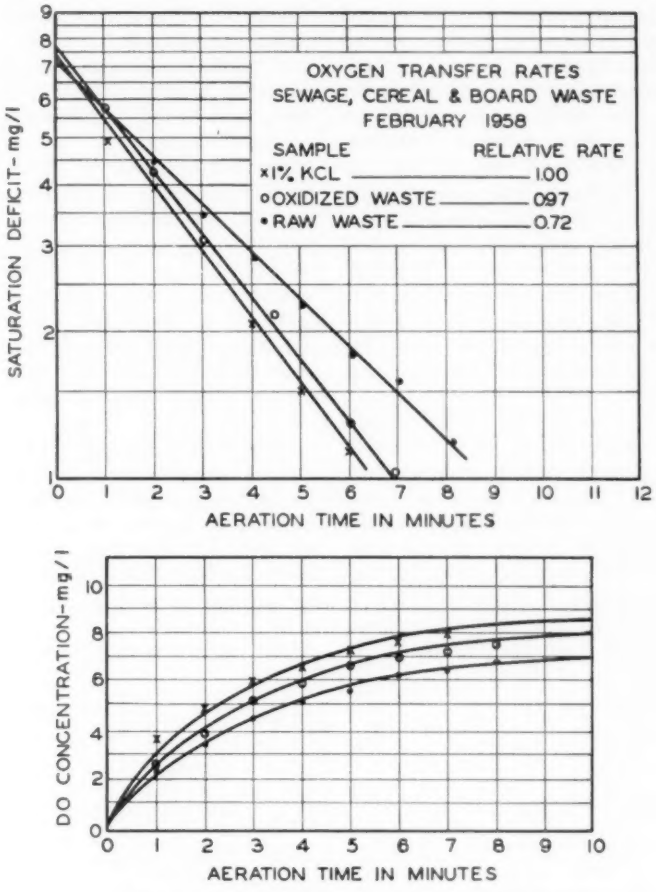

FIGURE 2.—Oxygen transfer rates for combined waste.

control to 100 per cent, and simultaneously increased the relative rate of oxygen transfer from 72 to 98 per cent. It was apparent from these results that special consideration would be required in the selection and spacing of aeration equipment in a prototype aerator to compensate for the inherently poor transfer properties in the waste and the reduced oxygen driving force resulting from a low saturation level. The change in the relative transfer coefficient and saturation level with aeration time can be compared with similar data obtained by Eckenfelder *et al.* (4) for various industrial wastes.

Process Evaluation

In the evaluation of process performance it is convenient to arrange the major system variables in a single term expressive of the intensity of process operation under varying loading conditions. Practical nomenclature has evolved a parameter based on the ratio of the weight of applied organic load to the product of sludge weight and aeration time. Expressed in practical units the loading factor has the

dimensions of pounds of BOD applied per pound of aerating sludge per day of aeration time.

Fundamentally, the loading factor contains the three primary determinants of the effectiveness of treatment. However, the tacit assumption involved in its use is that sludge weight and aeration time are interchangeable and exert an equal and linear effect on process performance. Repeated analyses of actual plant operation have demonstrated that such interchangeability is valid only within certain defined limits of aeration time and sludge loading.

In this particular study, the over-all rates of BOD removal were evaluated from 16 separate runs employing various ratios of applied BOD to active solids for an aeration period of 4 hr. The relationship between process loading expressed in pounds of BOD applied per pound of sludge per day of aeration and process removal expressed on a similar rate basis is shown in Figure 3. The loading levels investigated varied from 0.5 to 2.1 lb BOD per pound of sludge per day, and included a sludge loading range of from 0.08 to 0.4 lb BOD applied per pound of sludge.

As demonstrated in Figure 3, the average efficiency of BOD removal remained substantially constant at 88 per cent. The loading-removal relationship illustrated in Figure 3 revealed that the combined waste possessed a treatment potential substantially higher than the operational characteristics associated with the domestic sewage fraction indicated (8) (9).

Subsequent analyses of loading-removal relationships, under varying sludge loading levels and after detention times ranging from 30 min to 4 hr, demonstrated that the correlation shown in Figure 2 was valid only for an aeration period of approximately 4 hr.

The sludge settling characteristics,

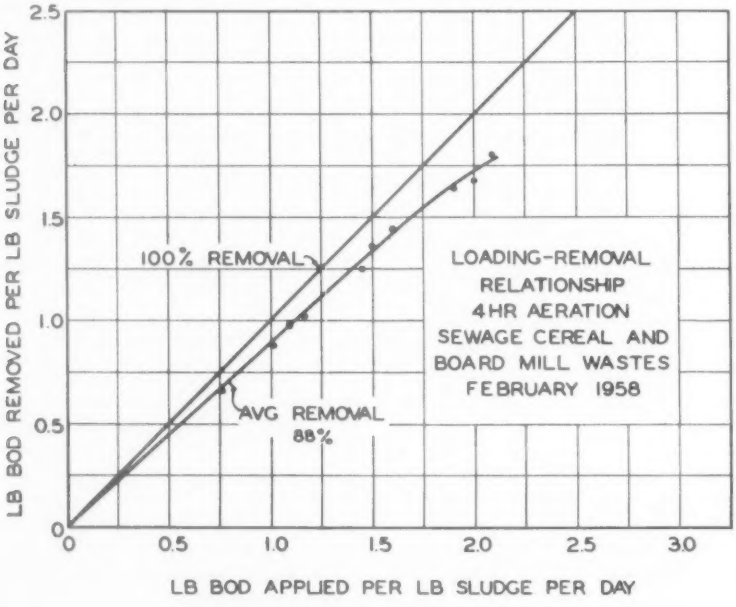

FIGURE 3.—BOD performance data.

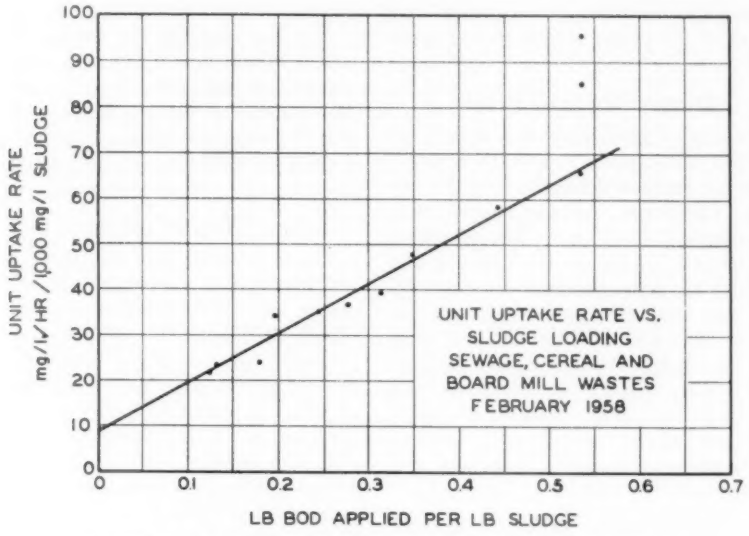

FIGURE 4.—Correlation of unit uptake rate with applied loading.

obtaining under the span of loading intensities investigated, displayed no significant correlation with process loading. The sludge volume index averaged below 75 for all the loadings investigated. It is believed that the concentrations of alum contained in the board mill wastes materially enhanced the flocculation characteristics of the sludge and contributed significantly to sludge stability.

Oxygen Requirements

In order to evaluate the relative effects of increased sludge loadings on the oxygen demand characteristics and activity of the system, unit uptake rates were measured polarographically for each of the sludge loadings reproduced in the test cylinders. A correlation of average unit uptake rate after four hours' aeration with applied loading is shown in Figure 4. The data demonstrated that the unit activity of the sludge, expressed in terms of unit uptake rate per 1,000 mg/l of mixed liquor sludge, increased about 75 per cent for a 100-per cent increase in loading intensity. This relative change with loading was approximately 3 times as great as the change observed for normal domestic sewage under similar loading conditions (10).

The rapid increase in unit demand rate with elevated loadings can be directly related to the high fraction of the raw waste BOD in dissolved form (53 per cent) which was significantly increased after primary sedimentation (75 per cent), and the inherent activity of the waste as expressed by the BOD velocity constant (0.28). A unit increase in loading with this waste mixture presented considerably more soluble and rapidly oxidizable material for sludge stabilization than could be expected from normal domestic sewage (1).

An extrapolation of the curve to zero loading level indicates a minimum demand rate of 8 mg/l per hour per 1,000 mg/l sludge. This base rate represented the quantity of oxygen required to support sludge autoxidation (3) (11). Considering the ultimate oxygen equivalent of activated sludge to be 1.4 mg/l oxygen per mg/l of sludge (12), the base rate was

equivalent to a sludge oxidation rate of about 14 per cent per day of aeration.

Oxygen Demand Profile

Figure 5 illustrates the change in oxygen unit uptake rate with aeration time for various sludge loading intensities. The oxygen demand profiles were constructed using the average values of the ratio of the demand rate at any time to the corresponding 4-hr average demand rate for each sludge loading level. The 4-hr average demand rates for the sludge loadings shown in Figure 5 were defined by the correlation shown in Figure 4. The average ratios observed under the varying sludge loadings reproduced in the test cylinders were as follows:

Time of Aeration (hr)	Ratio of Demand Rate to 4-hr Avg Demand
0	1.70
1	1.08
2	0.88
3	0.81
4	0.76

The maximum observed deviation from the average profiles, shown in Figure 5, at any particular sludge loading was limited to ± 12 per cent. Oxygen consumption profiles similar to the one illustrated in Figure 5 provide valuable data concerning the variation in demand rate with the normal fluctuations in loading to be expected in the prototype aerator and provide a basis for selection of aeration equipment.

Oxygen Balance

The over-all oxygen requirements to support active oxidation and stabilization of the combined wastes are shown in Figure 6. The curve was prepared by correlating the total oxygen consumed, expressed as pounds of oxygen per pound of sludge per day of aeration, after four hours of aeration, with the total quantity of BOD removed reduced to a similar unit rate basis. The method of analysis employed was based on the oxidation-synthesis relationship employed by Smith (13) and Eckenfelder and O'Connor (14). The validity of the relationship shown in Figure 6 is predicated on the assumption that after four hours' aeration, BOD removal was obtained solely from oxidation-synthesis and not from the storage of unmetabolized BOD through sludge adsorption.

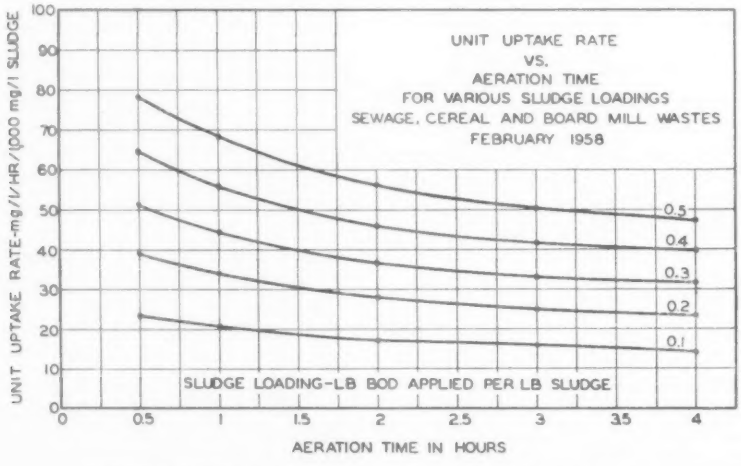

FIGURE 5.—Change in oxygen unit uptake with aeration time.

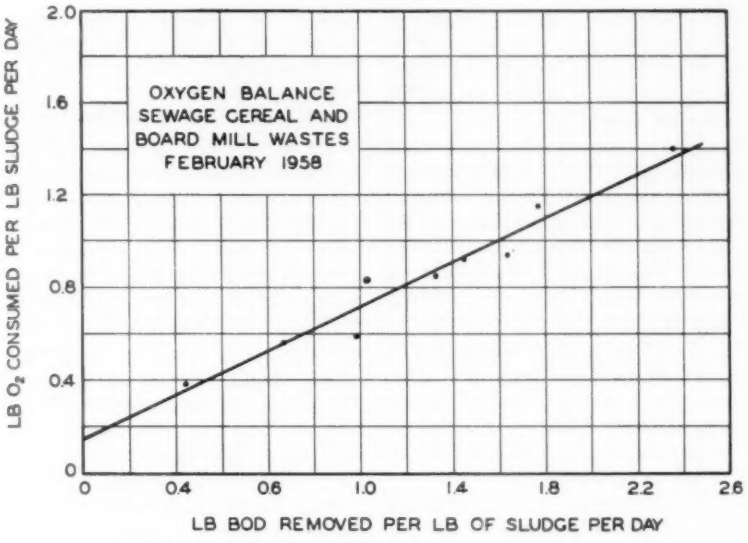

FIGURE 6.—Oxygen requirements for combined wastes.

The average fraction of the BOD removed which underwent direct oxidation is represented by the slope of the line of best fit. For the wastes studied, the over-all oxygen requirement was calculated at 53 per cent of the BOD removed, or about 15 per cent greater than the oxygen requirement for the stabilization of an equal amount of domestic sewage.

The unit oxygen requirement shown at zero loading represents the average rate of sludge oxidation.

For 4 hr of aeration the rate of sludge oxidation averaged about 0.15 lb oxygen per pound of sludge per day or an equivalent mean unit uptake rate of 6.5 mg/l per 1,000 mg/l of aerating sludge. This base rate compared favorably with the minimum requirement obtained from the extrapolation of the unit demand rates in Figure 4. Assuming an oxygen-sludge equivalent of 1.4, 0.15 lb oxygen per pound of sludge per day was equivalent to an autoxidation rate of about 11 per cent per day. The divergence between the values obtained from Figures 4 and 6 was within the experimental limits of the analysis.

The data contained in Figure 6, in conjunction with the loading-removal relationship in Figure 3 and the demand profile shown in Figure 5, can be used to estimate over-all process efficiency and momentary oxygen requirements for aeration periods of about four hours' duration. For example, when loading a prototype aeration tank at a level of 1.2 lb BOD per pound of sludge per day, an average BOD removal of about 88 per cent, or 1.06 lb BOD per pound of sludge per day, can be expected (Figure 3). The corresponding average oxygen requirement can be estimated from Figure 6. A removal of 1.06 lb BOD per pound of sludge per day corresponds to a unit oxygen requirement of about 0.75 lb oxygen per pound of sludge per day. As a process loading of 1.2 is equivalent to a sludge loading of 0.2 lb BOD per pound of sludge for a 4-hr aeration time, the unit oxygen demand profile can be traced by referring to Figure 5. Conversion of these unit rates to

demands, expressed as a weight of oxygen per unit time, can be made by multiplying the unit rates by the quantity of mixed liquor sludge carried in the aeration tanks.

The oxygen balance can also be used to estimate the average excess biological sludge produced in the aeration process for any loading condition (14). The slope of the oxygen balance in Figure 6 demonstrates that 0.53 lb oxygen were required to oxidize 1 lb of 5-day BOD to CO_2 and H_2O. If it is assumed that BOD removal was obtained through oxidation and synthesis alone, the oxygen equivalent of the quantity of 5-day BOD synthesized to new sludge was (1–0.47) or 0.53 lb of oxygen per pound of 5-day BOD removed. As the total oxygen consumed remains constant, regardless of the mode of expression of BOD removal, the oxygen equivalent of the BOD synthesized to new sludge can be converted to an ultimate BOD basis by employing the first stage BOD equation. Employing an oxygen-sludge conversion factor of 1.4 pounds of oxygen per pound of sludge (12) found to be applicable for various types of activated sludge, the actual quantity of sludge produced per pound of ultimate BOD removed can be calculated as (0.51/1.4) or 0.36 lb.

Again recognizing that the quantity of sludge produced remains constant for a given oxygen consumption, an expression for sludge production can be derived in terms of 5-day BOD removal. Employing the relationship between ultimate and 5-day BOD, as indicated by the first stage BOD equation, the amount of 0.38 lb biological sludge produced per unit 5-day BOD removed is found. For practical purposes a value of 0.4 can be used to estimate sludge production.

The extent of sludge autoxidation was estimated from Figure 6 at approximately 10 per cent per day. Therefore, the net quantity of biological sludge produced can be approximated by deducting 10 per cent of the weight of aerator solids from the amount of sludge generated through BOD removal.

Initial BOD Removal Characteristics

In an attempt to approximate the extent of waste clarification and BOD removal resulting from the initial mixture of return sludge and primary effluent in a prototype aeration tank, average BOD removals were correlated with aeration time in the manner shown in Figure 7. The growth ratio (12) represents the ratio of the weight of active sludge present in the aerating mixture after any time to the initial weight of active sludge present. According to the kinetics of log growth (15) the relative increase in the quantity of active sludge through bacterial synthesis can be expressed as an exponential function of time. A plot of the log of the relative increase in sludge quantity against time should theoretically result in a linear correlation.

The growth ratios, shown in Figure 7, were computed using the quantity of BOD removed as a base. The BOD removals after any aeration time were taken from average curves drawn through the observed removal points. For the lower values of sludge loading the observed removals adhered closely to the average curve. As sludge loading increased, the individual points diverged significantly from the average removal curve. The conversion to equivalent sludge produced was made by employing the fraction of the total BOD removed which was synthesized to new sludge as obtained from Figure 6, and an assumed oxygen-sludge equivalency factor of 1.4 (12). In this manner equivalent growth ratios were approximated for the average BOD removal at the various sludge loading levels shown in Figure 7.

The non-linear variation with time, after increased aeration periods, may be attributed to the increase in the difficulty at which the BOD oxidized after initial aeration and the decrease

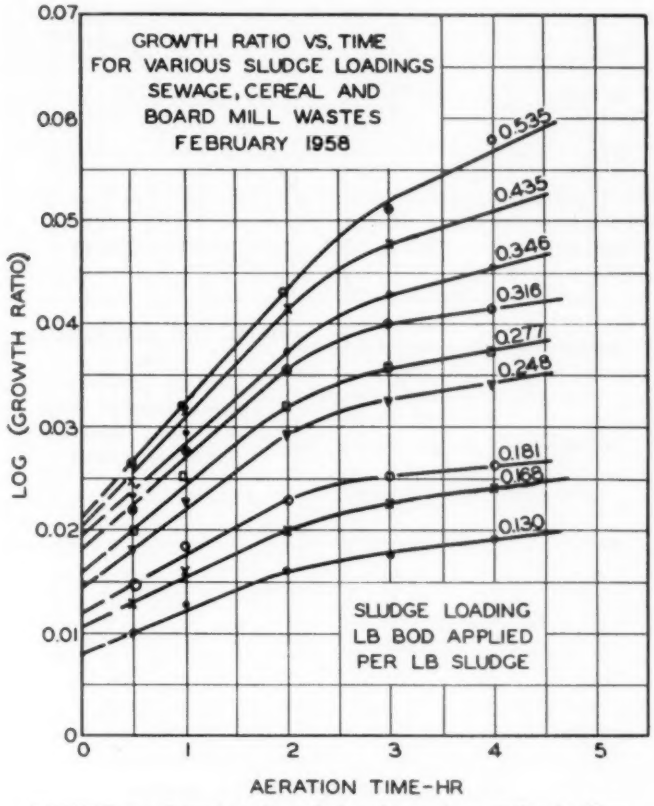

FIGURE 7.—Growth ratio and time for various sludge loadings.

in sludge activity (Figure 4) commensurate with a reduction in sludge loading through BOD removal and sludge production.

A projection of the linear portion of the curves to zero aeration time results in an initial growth ratio illustrative of BOD removal through "adsorption" on the sludge floc. As shown in Figure 7, the initial removals increased with an increase in sludge loading intensities.

A correlation of initial removals obtained from Figure 7 expressed as pounds of BOD removed per pound of sludge against the applied sludge loading intensity is shown in Figure 8. The fraction removed by adsorption remained essentially constant, at about 40 per cent of the applied load, up to a loading of about 0.35 lb BOD per pound of sludge. The fraction adsorbed appeared to decrease significantly at loadings over 0.35 and reached a value of 25 per cent at a loading of approximately 0.55 lb BOD per pound of sludge.

Over-All Process Operation

In order to evaluate the operation of the laboratory-scale treatment system without qualifying the relationships with a specific loading level or aeration time, the average BOD removal data were arranged as shown in Figure 9. The average BOD removal efficiencies obtained after aeration periods varying from 30 min to 4 hr were

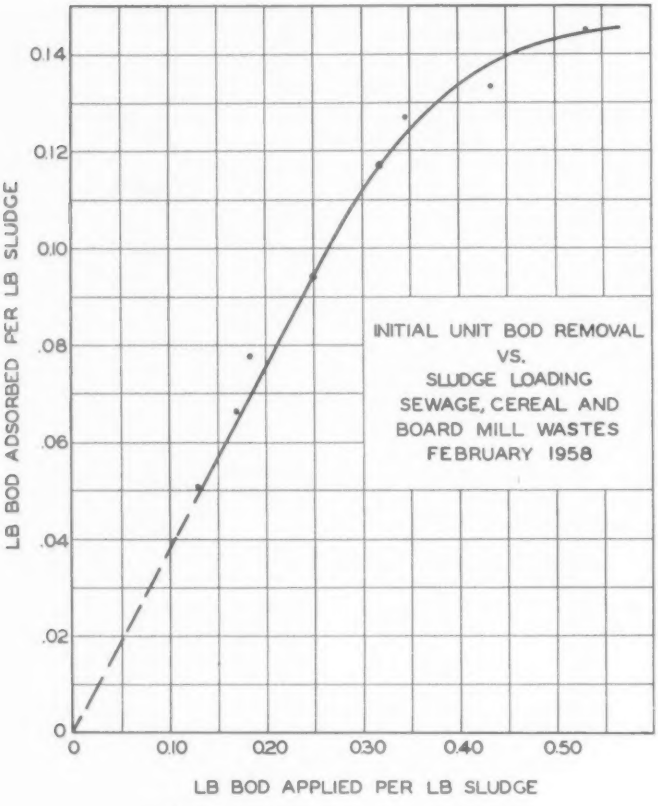

FIGURE 8.—BOD removal by adsorption.

plotted against their respective sludge loading intensities. The resulting curves clearly demonstrated the manner in which sludge loading and aeration time affected the extent of BOD removal.

For any one particular value of sludge loading, the additional removal efficiency obtained with a unit increase in aeration time decreased as the aeration period was extended. The incremental change in reduction efficiency with increasing aeration time illustrated the non-linear dependency of BOD removal on aerator detention. The curvilinear shape of each removal curve, at any constant aeration time, revealed the exponential variation of BOD removal with sludge loading. The family of curves illustrates that an estimate of aerator performance on the basis of an over-all loading, expressed in terms of pounds of BOD applied per pound of sludge per day, would be valid only within specified limits of loading intensity and detention time. The change in removal efficiency with aeration time also demonstrates that essentially complete stabilization of the waste was obtained after four hours and that detention in excess of this period would result in little process improvement other than a reduction in the quantity of sludge carried in the system through autoxidation.

As a guide to the mechanics of the reactions governing BOD reduction, the general areas of adsorption, adsorption coupled with oxidation-synthesis, and oxidation-synthesis alone were approximated by the dashed lines in Figure 9. The lower boundary, representing the limit of BOD removal obtainable through adsorption only, was drawn using the initial removal percentages indicated by the correlation of adsorption with sludge loading (Figure 8). The upper boundary, representing the limit of removal through a combination of initial adsorption and subsequent oxidation of the initially stored material, was drawn on the premise that in order to remove a unit weight of BOD exactly twice the amount initially removed by sludge adsorption, the originally stored material must be stabilized through bacterial metabolism. The validity of this assumption is predicated on a preferential metabolism of organic matter by the active sludge. Oxidation-synthesis is assumed to proceed immediately after the initial adsorption of organic matter, utilizing the initially removed material for subsequent energy requirements. A more definitive estimate of the rate of stabilization of initially adsorbed load requires the comparison of observed BOD removals with the quantity of BOD removed through oxidation-synthesis as computed from oxygen consumption tabulations. The limited batch-type experiments conducted precluded any such detailed comparison. However, oxygen consumption calculations indicated that a minimal quantity of organic matter at least equal to the initially adsorbed load had been removed by oxidation-synthesis at the time limits inscribed by the upper boundary. Areas on the graph above the second boundary line therefore represent BOD reductions obtained essentially through direct oxidation and synthesis of the organic matter removed.

Using these general boundaries, the approximate minimum detention times required to produce a stable sludge can be estimated. For example, at an applied loading of 0.3 lb BOD per pound of sludge, a detention time in excess of 2 hr would be required to insure the oxidation of the initially adsorbed BOD. As a significant lead of

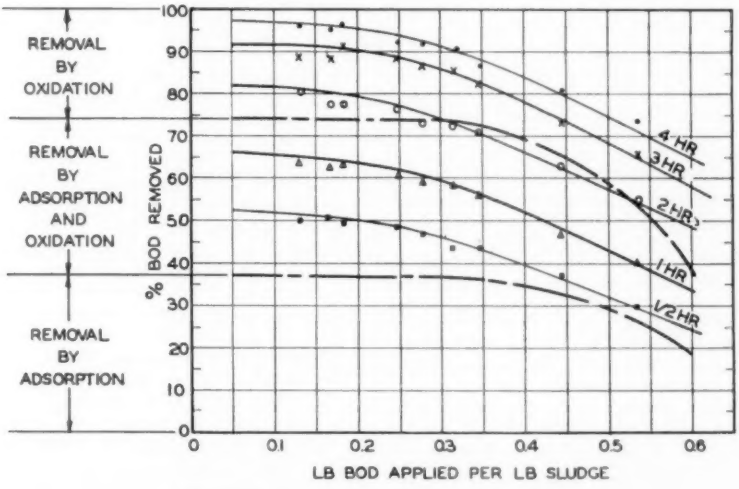

FIGURE 9.—Average BOD removal data.

adsorption over oxidation produces a sludge of questionable settling properties (8) a detention time of less than about 2 hr could be expected to produce a sludge containing a significant fraction of unoxidized organic matter and exhibiting poor settling qualities. The return of a sludge of this character to the aeration system would eventually result in failure of the process.

The arrangement of laboratory data in the manner shown in Figure 9 provided useful information concerning the relative economies resulting from various process modifications and presented a rational basis from which subsequent pilot-scale studies could be conducted. For example, if at the applied loading of 0.3 lb BOD per pound of sludge a 2-hr aerator could be operated in parallel with a unit producing a detention time in excess of 2 hr, the stabilized excess sludge from the larger unit might well be used as return sludge for the short-term aerator. The stabilization of the return sludge for the smaller aerator in the larger unit would tend to regenerate its initial removal and clarification properties for reapplication in the short-term aerator. The settling characteristics of the underoxidized sludge produced in the short-term aerator might be enhanced by omitting primary sedimentation of the feed waste to the unit.

Summary

The treatment of combinations of sewage and industrial wastes requires special consideration of process selection and design. Laboratory-scale treatment studies often provide valuable information concerning process feasibility and stability. The results of these small-scale investigations, while limited for direct application in design, can be used to estimate the economies resulting from process modification and direct subsequent pilot-scale studies. An illustrative example of the methods employed and the analyses involved have been presented for a mixture of sewage, cereal effluent, and board mill wastes.

Acknowledgment

Grateful acknowledgment is made of the assistance of Mr. Dean E. Sheriff, Industrial Waste Chemist, of the Battle Creek, Mich., Sewage Treatment Plant, in compiling and evaluating the laboratory data.

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MEETINGS OF INTEREST

1959

Nov. 29–Dec. 2 — **American Municipal Association,** Brown Palace Hotel, Denver, Colo. Patrick Healy, Jr., Executive Director, 1612 K Street, N. W., Washington 6, D. C.

Nov. 29–Dec. 4 — **American Society of Mechanical Engineers,** Chalfonte-Haddon Hall Hotel, Atlantic City, N. J. ASME, 29 West 39th Street, New York 18, N. Y.

Nov. 30–Dec. 4 — **Exposition of Chemical Industries,** Coliseum, New York, N. Y.

Dec. 1–2 — **North American Pulp, Paper, and Paperboard Industrial Wastes Conference,** Edgewater Beach Hotel, Chicago, Ill. Russell L. Winget, Executive Secretary, National Council for Stream Improvement, Inc., 271 Madison Avenue, New York 16, N. Y.

1960

Jan. 4–8 — **Course on River Pollution, Sewage Disposal, and Trade Waste Treatment,** University of Birmingham, Edgbaston, Birmingham, England. R. F. Wills, Civil Engineering Dept., The University, Edgbaston, Birmingham 15, England.

Jan. 8–11 — **Sanitary Engineering Conference,** Sanitary Engineering Division of ASCE, Netherland-Hilton Hotel, Cincinnati, Ohio. W. H. Wisely, Executive Secretary, 33 West 39th Street, New York 18, N. Y.

Jan. 27–28 — **Second Sanitary Engineering Conference,** University of Illinois, Urbana, Ill. William J. Downer, Asst. Chief Sanitary Engineer, Dept. of Public Health, Springfield, Ill.

OIL REFINERY WASTE TREATMENT IN KANSAS*

By Carl F. Hodgkinson†

Chief, Water Pollution Control Section, Kansas State Board of Health, Topeka, Kans.

Slightly more than ten years ago the Kansas State Board of Health undertook a new approach to water pollution control. In spite of the many sewage and industrial waste treatment plants that had been constructed over the years, the gap between the pollution load to be treated and existing treatment facilities continued to widen.

It was decided that the basin-wide approach would improve the program and a survey of the Kansas River basin, which drains roughly the northern half of the state, was initiated. The investigation was followed by a report, hearings, and a uniform pollution abatement policy which was adopted by the Board in 1950.

Investigations and uniform pollution abatement policies followed for the Walnut, Arkansas, and Little Arkansas Rivers. In addition, a cooperative program has been developed by the five states along the lower Missouri River.

As the results of these programs, much progress has been made in the abatement of stream pollution. Since 1950 over 200 municipal sewage treatment plant projects have been completed, 22 are under construction, and 11 more are in the process of advertising for bids, signing contracts, and preparing for actual construction.

Refining in Kansas

Industrial progress has generally matched that of municipalities. Since petroleum production and refining is an outstanding Kansas industry, waste prevention, control, and treatment has been noted in this field. Ten of the 12 refineries in Kansas are located in river basins covered by pollution abatement policies and the remainder are in the Verdigris basin. Six of these refineries are located in the Walnut and Arkansas basins. Consequently most of the activity in refinery waste treatment has occurred since the adoption of these policies.

Refinery Wastes Abatement Policy

The pollution abatement policy as applied to oil refineries was as follows:

1. At minimum stream flows the BOD exerted on any section of the stream shall not reduce the DO content below 4 mg/l.

2. Oil refinery wastes should be substantially free of toxic substances, including metallic ions, phenolic compounds, chemical or immediate oxygen demand, oils, alkalies, and acids, before they are discharged to a watercourse.

In addition to these requirements, two other policies were indicated for the review of reports, plans, and specifications:

1. Collection and retention facilities should be provided for 5 in. of runoff from the refinery area if the collected storm water could be returned to the treatment process within about a 5-day period. If water conservation was attempted the facilities were to be adequate for 7½ in. of runoff with the

* Presented at the Ninth Oklahoma Industrial Wastes Conference; Oklahoma State Univ., Stillwater, Okla.; Sept. 24–25, 1958.

† Present address: c/o Truman Schlup, Consulting Engineers, Kansas City, Kans.

water reclaimed in a period of about 20 days.

2. River basin studies and pilot plant research had indicated the importance of total first stage BOD. The first stage BOD of refinery waste will approximate 3 to 5 times the 5-day BOD as compared to the 1.5 ratio common in domestic sewage. The deoxygenation rate is similar to normal sewage. Consequently, the equivalent of 60 days detention of the wastes was required.

Recommended Investigation Methods

In 1954 the Board of Health prepared an outline of a recommended procedure by which a refinery could study its waste and develop design factors. The outline indicated items to be studied pertaining to process flow and storm water runoff. In addition, composite samples were to be collected on the main waste stream with in-plant sampling where indicated by analysis of the combined effluent. The following tests were to be made:

1. Nitrogen (organic, ammonia, nitrite, and nitrate).
2. Oil as both separable and emulsified.
3. Oxygen demand as 5-day BOD and immediate.
4. Dissolved oxygen.
5. Phenols.
6. Alkalinity as total and phenolphthalein.
7. pH.
8. Metals such as lead, copper, chromium.
9. Chlorides.

This data was to be assembled with other basic engineering factors and presented in a report along with the results of any laboratory or pilot plant studies.

Typical Study Results

The studies undertaken revealed a variety of problems. Although each refinery had individual characteristics, a composite of report conclusions would probably read as follows:

1. The existing oil separator facilities were not removing enough free oil. Some waste streams contained relatively high concentrations of emulsified oil. Sludge removal from the separator was a problem.
2. The flow on any particular day did not vary greatly from the 24-hr average but daily average flows varied as much as 50 per cent, depending on temperature, rate of production, variations in raw water quality, and other factors.
3. Phenols, sulfides, and ammonia constituted major problems.
4. The waste pH was relatively constant and usually alkaline.
5. Chlorides were a matter of concern and total dissolved solids were relatively high.
6. Large volumes of storm water runoff from adjacent property crossed the refinery grounds.

Action by Industry

Several changes in refinery waste prevention and control became apparent soon after the reports were completed. All of these changes may not be directly attributable to pollution abatement but were definitely allied.

All of the refineries covered by pollution abatement policies have made tangible progress in controlling the waste discharged. Treatment facilities have been completed at three refineries; two refineries have completed the first phase and embarked on the second phase of construction; treatment plants are under construction at two other installations; and a contract is near for another plant.

Reuse of Waste

After completion of the waste studies and design of the proposed treatment facilities, it became apparent that the treated effluent would be nearly equal in quality to the stream flow.

This was necessary in most instances because there was little or no dilution available at times of low flow. The treated waste was then recognized as a valuable water resource, especially during the drought, and many refineries prepared to reclaim and recycle this water.

Air Cooling

The studies also revealed that a significant part of the waste stream came from the contamination of cooling water through leaks and interconnections. This, together with drought, prompted the extensive use of air cooling devices. These air cooled units are limited to relatively high temperature streams (lower limit in the vicinity of 115 to 120°F). However, they do have other advantages besides pollution control in that greater flexibility can be obtained, temperature control is easier, and less maintenance is required.

These two factors are emphasized when comparing the unit amounts of water used by Kansas refineries with amounts used in other refineries. Almost without exception, Kansas refineries process a barrel of oil with less than a barrel of water. The average is near half a barrel and some refineries are using less than a third of a barrel of water per barrel of oil processed. Water usage on a national basis usually exceeds 2.5 bbl of water per barrel of oil processed, and a water demand as high as 10 bbl is reported.

Waste Concentration

Most of the refineries found it possible by minor in-plant changes to produce a concentrated caustic waste stream which was extremely high in phenols and BOD. A market for this material was available, although shipping costs made it a marginal economic enterprise. However, from a stream improvement standpoint it is practical, and as a result many tank carloads of polluting material are being hauled out of the state for reprocessing.

Nearly all of the refineries found that sulfide, ammonia, and in some cases phenol, contributions to the waste effluent could be substantially reduced by collecting small process streams and directing this flow to a stripping tower. It is said that the most efficient stripping units have good flow distribution inside the tower on a counterflow principle, use steam as a stripping gas, and operate at temperatures from 200 to 300°F.

Runoff

The refineries are about evenly divided as to choice of providing retention capacity for 5 in. of storm water runoff or retaining 7½ in. for reuse. Initially, some refineries indicated the opinion that this requirement was excessive. Rainfall studies have confirmed that 5-in. rains during a period of 1 to 3 days can be expected relatively frequently. Runoff contains oil and also contains BOD ranging from 10 to over 100 mg/l, depending on the rate of precipitation, cleanliness of the plant area, and length of the preceding dry cycle. Frequently short, intense local rains flush this pollution into the stream without a corresponding increase in the stream flow.

Subsurface Disposal

Two refineries have chosen to make use of deep injection wells as a means of final disposal of their wastes. This method of disposal is relatively expensive and carries a certain amount of calculated risk. However, downstream conditions may justify this expense and risk. Injection well disposal requires that the water be not only free of oil and turbidity but also that the water must be stable chemically and preferably slightly aggressive toward the receiving formation. Stabilizing water at ground surface temperatures and pressures is a major problem but the problem becomes more complex at

the temperatures and pressures likely to be encountered in the disposal formation.

The solubility of most ions varies directly with temperature but the solubility of some important compounds such as calcium sulfate increases with temperature to some maximum value, then decreases as temperature increases. Also, a shift in equilibrium may result in the release of a gas harmful to the system. Carbonate balance will likely be most significant in terms of volume and with respect to clogging of the receiving formation, but carbonate ions are relatively easy to treat. Acidizing of the well will be effective in removing carbonate clogging in the formation.

The reduction of chromates, which may be used in the cooling system, may be accomplished by hydrogen sulfide. Chromic salts formed by such reduction will precipitate gelatinous masses which cannot be redissolved by normal acidizing techniques. Calcium sulfate is very difficult to remove or redissolve if a precipitate is formed. Other less common compounds are also potential sources of trouble in a deep disposal system.

As a result of these problems, extensive pretreatment of the waste prior to subsurface disposal is required. Because of the expense involved and because water conservation policies require that no more water be destroyed than absolutely necessary, it is essential that the quantity of waste discharged be reduced to a minimum. Small waste streams which are high in total dissolved solids such as desalter water and zeolite filter recharge water are discharged directly to the pretreatment facilities. All of the other flow is "bottled up" so that cooling tower blowdown is the principal waste stream. Approximately 10,000 mg/l of total dissolved solids is the upper limit for water reuse in this fashion. This concentrated waste stream then usually passes through a conventional gravity oil separator followed by an air flotation basin. Chemical stabilization is accomplished by coagulation with lime, alum, and coagulant aid and is clarified in a solids contact unit. After the addition of acid for pH adjustment well below neutral and the addition of chlorine for disinfection, the waste is ready for discharge to the well. Caution must be exercised to be sure that air does not enter the injection system.

Oxidation Ponds

Six refineries have selected oxidation ponds as the principal treatment device. This method requires real care in management in order to assure successful operation. If a pond is to operate efficiently the quality of the effluent discharged to the pond must be controlled. In some cases, refineries will find it necessary to pretreat the waste biologically before discharging to the pond. All permits issued to date to refineries by the Kansas State Board of Health covering oxidation pond installations have been conditional. These provisions have indicated that the permit is subject to a satisfactory effluent being produced and that additional pretreatment may be required.

On the other hand, oxidation ponds do offer several advantages if the land area is available. Ponds require a much simpler type of maintenance and greater flexibility of routine maintenance is obtained. Maintenance usually consists of keeping weeds and grass mowed to prevent an insect problem and keeping the dikes in sound condition. It is relatively easy to provide extra storage for detention of the waste during extremely low receiving stream flows. This is particularly desirable where the river is used as a source of domestic water supply. Stabilization ponds have a great capacity to assimilate shock loads.

Reasonably complete primary treatment of the waste is being provided at several installations where oxidation

ponds are used. In addition to free oil separation, preaeration, air flotation, and chemical precipitation are used in various plants to prepare the waste for biological treatment. Stripping for sulfide and ammonia removal are believed essential.

In order to treat a refinery waste for discharge to an essentially dry stream the waste discharge to a stabilization pond should contain less than 20 mg/l total oil and should preferably be in the range of 10 mg/l. Sulfide content should be less than 15 mg/l. Phenols oxidize in ponds fairly rapidly if the concentration is not high enough to produce an inhibitory action. The phenol concentration should not exceed about 5 to 7,000 μg/l. Observations confirm that there is a time lag of approximately 25 days before any appreciable oxidation of ammonia occurs in a stabilization pond. If the pond effluent is to be nearly free of ammonia, the influent should have less than 12 to 15 mg/l for 60 days detention.

Oxidation ponds can be used as pretreatment devices also and ponds providing 120 days detention are in use and are being planned for other installations. A sound recommendation would appear to be the provision of a small pond ahead of any oxidation pond installation to trap any excessive oil which may pass through the separation facilities. At least two cells to be operated in series should be provided to minimize short-circuiting, but good distribution of the waste throughout the first cell is desirable.

A weed problem has been experienced in some places with domestic sewage waste stabilization ponds where long detention times are attempted. Seepage of the pond liquor into the soil, together with evaporation losses during summer months, has exceeded the influent volume and reduced the water depth to low levels and weeds have flourished. This same problem has not been encountered with refinery waste stabilization ponds. One explanation for this is that the small amount of oil which reaches the pond tends to reduce the rate of evaporation. Nevertheless, it is recommended that the pond bottom be made as nearly impervious as possible when a detention time of more than 60 days is attempted.

One refinery has chosen to install a trickling filter upstream from the pond. Trickling filter effluent will be recycled back to the water treatment facilities for reuse. This offers the advantage of providing a better quality and more stable water for reuse as well as assuring the success of the oxidation pond.

While reuse of water has eased the waste treatment problem, it has aggravated the problem of non-treatable dissolved solids such as chlorides and sulfates. Fortunately the chloride content of crude oil as it reaches the refinery is constantly being reduced and generally sulfates are still below tolerable limits.

Summary

In summary, oil refineries in Kansas have made great progress in controlling and preventing stream pollution during the past five years. Much knowledge has been added to the science of waste treatment through study and research, the design of plants, and the operation of the facilities. However, there are still a number of unknowns in refinery waste treatment. The refining processes and procedures are changing rapidly so that changes in waste characteristics can be expected. In fact there may be an entirely different treatment problem to solve a few years from now.

TOXIC EFFECTS OF METALLIC IONS ON SEWAGE MICROORGANISMS

By G. W. Malaney, W. D. Sheets, and R. Quillin

Respectively, Assistant Professor, Department of Bacteriology; and Research Professor, and Research Assistant; Water Resources Center, Ohio State University, Columbus, Ohio

One of the major problems facing state agencies regulating water pollution is the establishment of codes governing the discharge of toxic materials into municipal wastewater collection and treatment systems. The metal-finishing industries, for example, contribute wastes containing ions known to possess antibacterial properties—cations such as copper, zinc, nickel, and cadmium, and anions such as chromate and cyanide. For convenience, these ions will be referred to collectively as metallic ions.

Since these materials are capable of affecting microbial activity it is necessary to determine that concentration level of each ion which can be permitted in sewage plant influent without upsetting biological treatment. It then would be the responsibility of industry to remove any excess beyond this allowable concentration. Since such removal is a costly process, it follows that the control agency directly determines the level of cost required for industry treatment.

For several years the Ohio Department of Health has sponsored a study of the effects of metallic ions on treatment performance using trickling filtration and activated sludge treatment.

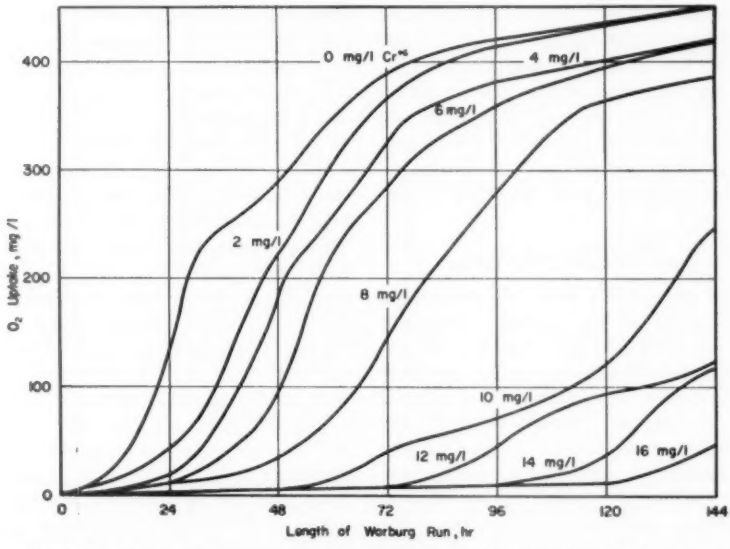

FIGURE 1.—Cumulative oxygen uptake by sewage microorganisms in the presence of various concentrations of hexavalent chromium.

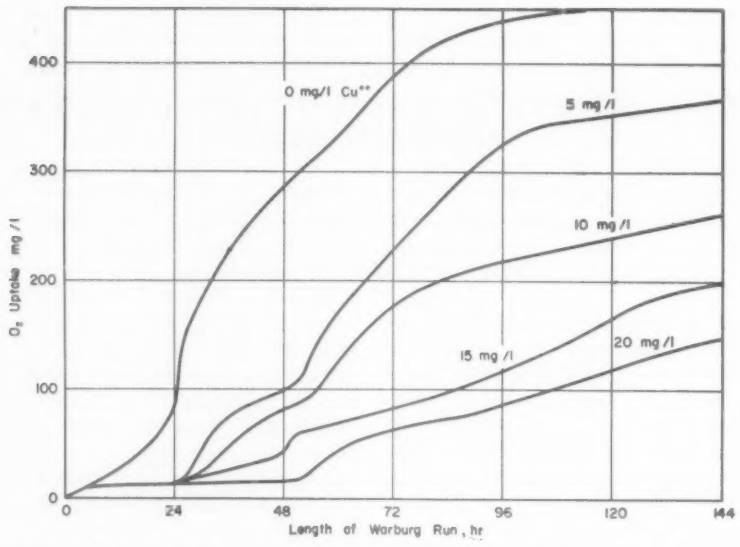

FIGURE 2.—Cumulative oxygen uptake by sewage microorganisms in the presence of various concentrations of divalent copper.

These studies have been carried on in a pilot waste treatment plant at the Water Resources Center on the Ohio State University campus. One of the correlated projects was an attempt to devise a laboratory method which might help predict the effects of a given ion on aerobic biological treatment units. The experimental method was based on the Warburg technique. The Warburg results revealed a rather surprising ability of the sewage microorganisms to recover from the toxic effects of metallic ions.

Materials and Methods

The parameter used in measuring the toxicity of the metallic ions was inhibition of oxygen uptake by the sewage microorganisms in the presence of various concentrations of a selected ion. A constant volume Warburg respirometer equipped with 125-ml flasks was employed. The ions investigated were chromium, nickel, zinc, copper, cadmium, and cyanide, which were added as aqueous solutions of CrO_3, $NiSO_4$, $ZnSO_4$, $CuSO_4$, $CdSO_4$, and NaCN. In this reporting the ions are given as concentrations of Cr^{+6}, Ni^{++}, Zn^{++}, Cu^{++}, Cd^{++}, and CN^-. Dawson and Jenkins (1) showed that sodium sulfate had no inhibitory effect in the concentration range used in the studies reported herein; therefore, the sodium and sulfate ions added with the test ion would presumably be inactive and are disregarded in the interpretation of the experimental results.

The reaction mixture for charging the Warburg flasks was prepared by placing 5.0 ml of simulated sewage in a 100-ml volumetric flask. To this was added sufficient test ion solution to give the desired final concentration. One milliliter of blended 24-hr settled sewage was added as seed. The flask was then filled to the mark with standard BOD dilution water. A 20-ml aliquot of this mixture was transferred to the reaction chamber of the Warburg flask. Oxygen utilization at 20°C was determined at intervals over a period of 144 hr. The range of concentrations used varied with the toxicity of the test ion. The simulated

sewage was lactose broth, prepared and sterilized according to the manufacturer's directions.

Experimental Results

Hexavalent Chromium

The curves representing the cumulative oxygen uptake by the seed microorganisms in the presence of 0 to 16 mg/l chromium are shown in Figure 1. These curves reveal several interesting points. Inhibition of the oxygen-utilizing activity of the microorganisms is shown by (a) a lower total oxygen uptake after a given time interval, and (b) a lag period before rapid oxygen uptake began, both compared with the chromium-free control. The curves also show clearly, by the sharp upswing following the lag, that acclimatization of the microflora to the presence of the metallic ion (i.e., recovery) occurred at all concentrations used. However, acclimatization was not complete at 144 hr except at concentrations near 2 mg/l, as shown by the fact that total oxygen uptake closely approximated the control uptake only at this concentration.

Divalent Copper

The curves for the cumulative oxygen utilization by the sewage microorganisms in the presence of 0 to 20 mg/l copper are plotted in Figure 2. The curves show the same general characteristics as those for chromium, namely, an initial lag in oxidation, varying in duration according to the concentration of copper, followed by recovery and more-or-less rapid uptake of oxygen.

Divalent Nickel

Oxygen uptake by the seed organisms in the presence of 0 to 16 mg/l nickel is shown in Figure 3. The organisms were inhibited for a variable period depending on the concentration of metal present. This lag was followed by oxygen utilization which was quite marked at 4 and 8 mg/l, but was much slower at 12 and 16 mg/l.

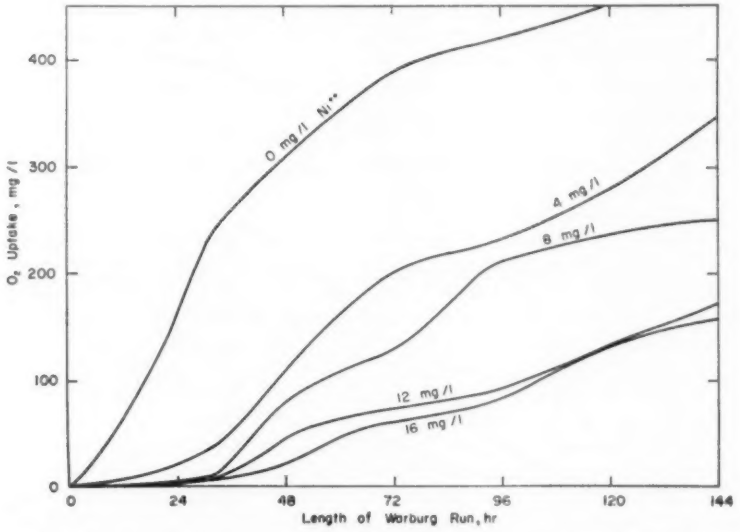

FIGURE 3.—Cumulative oxygen uptake by sewage microorganisms in the presence of various concentrations of divalent nickel.

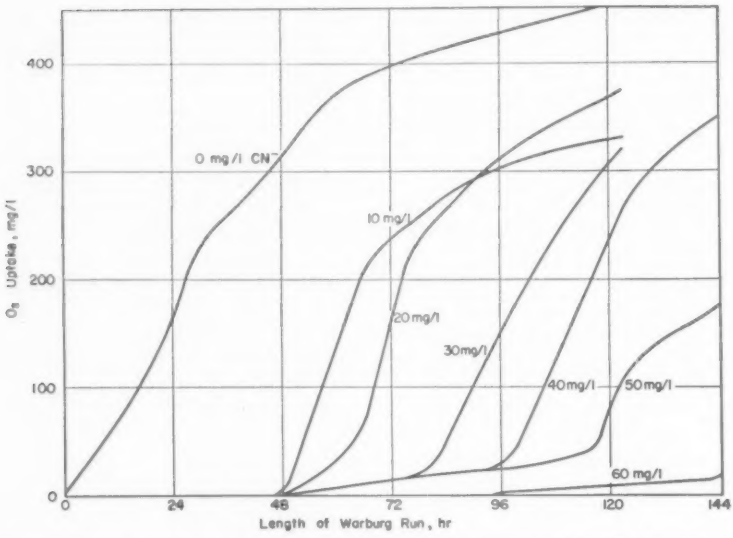

FIGURE 4.—Cumulative oxygen uptake by sewage microorganisms in the presence of various concentrations of cyanide.

Cyanide

The curves representing the cumulative oxygen utilization by the microorganisms in the presence of 0 to 60 mg/l cyanide are given in Figure 4. The curves again show that oxygen uptake was inhibited for a variable period of time depending on the concentration

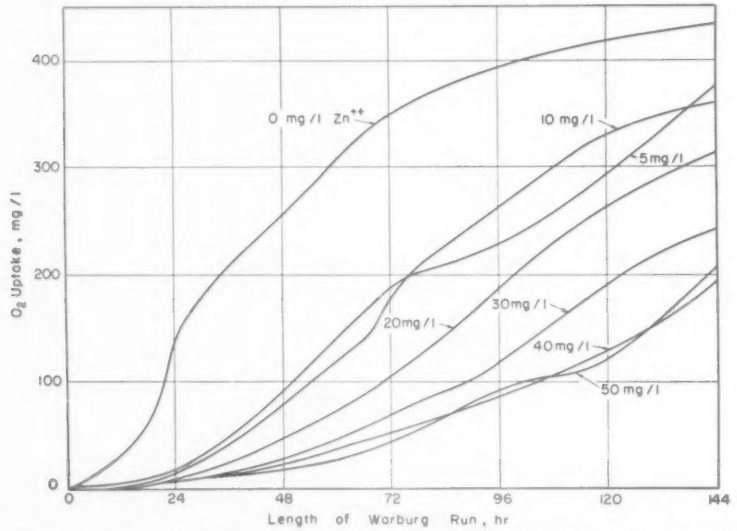

FIGURE 5.—Cumulative oxygen uptake by sewage microorganisms in the presence of various concentrations of zinc.

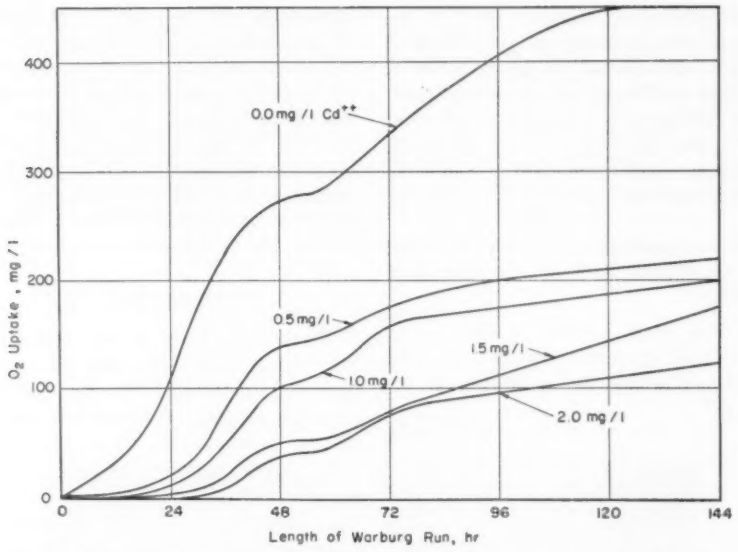

FIGURE 6.—Cumulative oxygen uptake by sewage microorganisms in the presence of various concentrations of cadmium.

of the ion, but that some measure of recovery was manifested at all concentrations employed, even at 60 mg/l.

Zinc

The cumulative oxygen uptake curves for the seed microorganisms in the presence of 0 to 50 mg/l zinc shown in Figure 5 reveal the same picture of initial inhibition and recovery as shown for the other metallic ions.

Cadmium

Although much more toxic than the other ions tested, cadmium at concentrations ranging between 0 and 2.0 mg/l had the same general effect as the other ions, as can be seen in Figure 6.

Discussion

The ability of the sewage microorganisms to recover their oxidative capacity under the experimental conditions selected was rather unexpected, since it had been anticipated that a constant concentration of a given inorganic ion would maintain roughly the same level of antibacterial activity in the relatively static situation existing in the Warburg flask, or even produce a steady deterioration in microbial activity. Actually, it is accepted as a general principle in the field of disinfectant action that bacterial survival is an inverse function of exposure time. But here apparently are antibacterial agents which become less toxic with increasing exposure time.

There are numerous instances on record where temporary deterioration occurred in biological treatment when a slug of toxic waste was received. In these instances the treatment recovered its removal efficiency after the flow of toxic waste was discontinued. This, however, represents recovery principally as a result of flushing the toxic materials out of the treatment plant. Such incidents show that the toxic action is inhibitory to the sewage microorganisms, rather than lethal.

The results reported here deal with a different situation—recovery in the presence of a presumably unchanging

concentration of metallic ion. A review of the literature of the effects of cations and anions on pure bacterial cultures and biological treatment processes disclosed a number of cases in which this type of recovery occurred, although the phenomenon was not always recognized as such (2) (3) (4) (5) (6) (7) (8) (9) (10).

Several possible mechanisms by which the organisms recover may be suggested:

1. The toxic nature of the ion is neutralized in some way by microbial activity, perhaps by oxidation to an insoluble oxide.

2. The initial ion to population ratio was high enough to inhibit oxygen uptake (respiration), but not multiplication of the organisms. Increasing numbers of bacteria reduce the ion to population ratio until eventually rapid oxygen uptake is resumed.

3. The bacterial population adapts to the use of the ion as a food material and thus removes the ion. This may be the case with cyanide, since a number of workers have reported that this ion is susceptible to bacterial oxidation.

4. The oxygen uptake in the presence of the ion results from the growth of one species or a few species of microorganisms of the original population which were less affected by the ion than the majority of the population. As the resistant organism grows and multiplies, oxygen uptake increases. Weed and Longfellow (8) have reported the occurrence of a copper resistant variant form of *Escherichia coli* in a population for which the same concentration of copper was inhibitory or lethal.

The capacity of the sewage microorganisms to acclimatize to the presence of the metallic ions tested suggests that the effect of shock loads of metal-finishing wastes will be transitory and may not permanently damage aerobic treatment. Obviously, the magnitude of the effect will depend on the concentration of toxic ion in the waste and the duration of toxic waste flow, since there is little doubt that these ions tend to concentrate in the floc in the aeration tank and in the slime of the trickling filter. These results also point up the fact that exposure time is an important consideration in the evaluation of toxicity data.

Summary

Warburg studies of the toxicity of metal-finishing waste ions on sewage microorganisms showed that, after a variable period of inhibition as evidenced by an initial lag in oxygen uptake, the organisms became acclimated to the presence of the metallic ion and recovered their oxidative capacity. Recovery, although seldom complete in the time interval employed, was quite definite in the range of concentrations used in this study.

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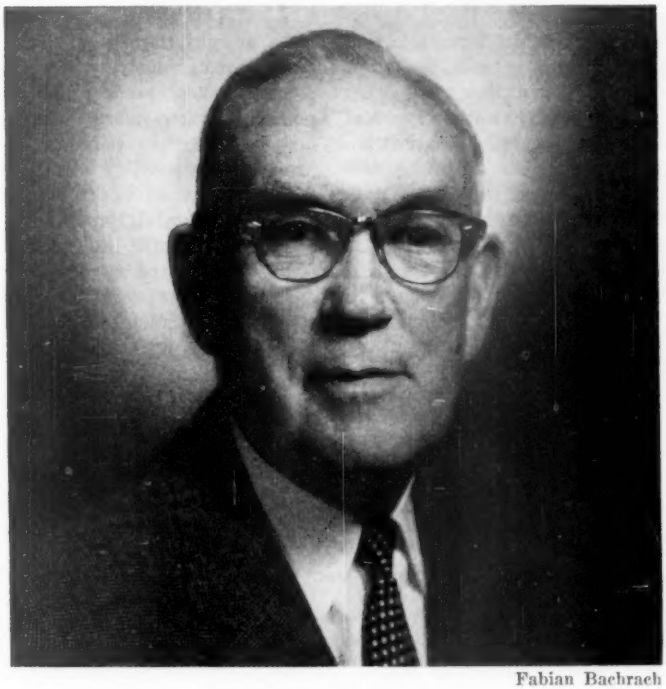
FRANK A. MARSTON ASCE PRESIDENT



Fabian Bachrach

Frank A. Marston, partner in the firm of Metcalf and Eddy, Boston, is the 1960 president of the American Society of Civil Engineers. He was installed at the annual meeting in Washington, October 19–23.

Mr. Marston, in following Francis S. Friel of Philadelphia, becomes the second successive sanitary engineer to head ASCE.

Stream Pollution

AQUATIC FUNGI IN WATER WITH HIGH WASTE LOADS

By Wm. Bridge Cooke and A. F. Bartsch

Mycologist, and Biologist, Water Supply and Water Pollution Research, Robert A. Taft Sanitary Engineering Center, USPHS, Cincinnati, Ohio

True aquatic fungi have been known for 135 years, but work with them during that time has centered around three fields of interest. Early observers noted that certain aquatic fungi grew around dead animals in the water such as insect larvae, flies, and other mature insects, and that other types of fungi grew on living fish. Later it became apparent that one or two species of aquatic fungi were associated with polluted waters in streams, sewer outlets, wastes from certain specialized industries such as sugar factories, and even on trickling filters in biological sewage treatment plants. Since the latter part of the nineteenth century there have been several mycologists searching intensively for aquatic fungi. As a result of these efforts a substantial body of literature has been developed around the aquatic fungi which are found in relatively clean waters including lakes, pools in streams, and ponds. These collectors have not similarly studied the populations of polluted waters, possibly because this habitat is unattractive to the aesthetic senses. Accordingly, there is only a limited literature on aquatic fungi found in polluted waters.

In 1951, Harvey (1) collected from streams throughout the Little Miami River Basin in Hamilton, Clermont,

TABLE I.—River Water Quality Data, North Branch, Potomac River, Maryland, Oct. 1956

Station	BOD (mg/l)	DO (mg/l)	pH	Notes
6	1	Near saturation	4–5	Acid mine drainage
7	—	—	—	Very clean, practically drinking water quality
9	20–40	3–7	—	High solids, COD, and alkalinity. Pulp and paper mill 1 mile upstream discharging untreated sulfate mill waste and sanitary sewage
14	5–10	6–8	—	20 miles below Sta. 9, still quite polluted. Small towns within 14 miles discharge untreated sanitary sewage
16	10–15	3–6	—	6 miles below Sta. 14. Rayon processing plant discharges untreated process and sanitary waste 1.5 miles upstream
19	8–10	3–7	—	8 miles below rayon plant, below Cumberland, Md., but above sewage outfall

TABLE II.—Fungus Species Found in Lytle Creek, Clinton Co., Ohio

Station	*Saprolegnia* sp. (sterile)	*Saprolegnia delica*	*Saprolegnia ferax*	*Dictyuchus monosporus*	*Achlya* sp.
8.7	—	X	X	—	X
7.6	—	X	X	X	X
7.2*	X	—	—	X	—
6.5	X	—	X	—	—
5.2	X	X	—	—	—
4.2	X	X	X	—	X
2.8	X	X	—	—	X
1.0	X	—	X	—	—

* Sewage treatment plant outfall; direction of stream flow is from Station 8.7 to Station 1.0.

Warren, and Clinton Counties, Ohio, in a search for aquatic fungi. He chose portions of streams which could be considered relatively lightly to heavily affected by pollution as evidenced by the nature of the communities through which these streams passed. He found few, if any, aquatic fungi actually living in reaches of the streams which were heavily polluted.

TABLE III.—Fungus Species Found in East Fork, Little Miami River, Batavia, Clermont Co., Ohio

Station	*Saprolegnia ferax*	*Dictyuchus monosporus*	*Achlya americana*	*Leptomitus lacteus*
Above Batavia	X	X	—	X
Below Batavia	X	X	X	—

From October 1954 to June 1958 an irregularly spaced series of tests was made to determine if it would be practical to assay populations of aquatic fungi for use as a parameter of water quality in stream pollution investigations. If a relatively rapid method could be found to demonstrate the aquatic fungus population of a stream, especially in the more polluted reaches, additional useful information could be made available to persons concerned with stream sanitation. At the same time the question of whether there is an aquatic fungus indicator of pollution could be answered.

Techniques

The technique used by Harvey was relatively simple. A sample of the stream consisting of water and stream bed materials was placed in a culture dish in the laboratory, and sterile, cracked hemp seeds were added. Within several days, if aquatic fungi were present, their zoospores would reach the hemp seed and there develop a colony in the form of a halo around the seed. This mycelium could be subcultured on fresh hemp seeds in sterile water in which carbon had been boiled and filtered off, or it could be subcultured on corn-meal agar slants.

In the studies reported here, other techniques were used, involving the use of bait. At first, the baits used

TABLE IV.—Fungus Species Found in East Fork, Little Miami River, Williamsburg, Clermont Co., Ohio

Station	*Saprolegnia ferax*	*Achlya americana*	*Achlya dubia*	*Dictyuchus monosporus*	*Olpidiopsis saprolegniae* var. *levis*	*Leptomitus lacteus*
Above Williamsburg	X	X	X	X	—	—
In Williamsburg	X	X	X	X	X	X
Below Williamsburg	X	X	X	X	—	—

were enclosed in cylinders made of ¼-in. mesh hardware cloth, stoppered at each end with corks. From one of the corks a steel wire skewer on which a piece of beef, a piece of apple, a whole date, and a rose hip or hawthorne fruit were impinged, projected into the cylinder. The cylinder, floating partially submerged, was tied to some more or less permanent object on the shore and left for a week. Then the baits were transferred to a container filled with water from the sampling location, returned to the laboratory, and placed in sterile carbon water with sterile cracked hemp seed. Another technique followed a suggestion by Höhnk and Bock (2). Bags of loosely woven nylon cloth, containing sterile, cracked hemp seed, were tied to the shore of the stream being sampled, and left for three days. These bags were returned to the laboratory in containers partly filled with water from the sampling site.

In one series of tests, aluminum tea balls were prepared in the laboratory by adding cracked hemp seed, assembling three on a string, wrapping, and sterilizing. These assemblies then were sent to a field survey team working on a tributary of the Potomac River. Each tea ball contained three hemp seeds and a multiple unit as described was used at each of six stations. One tea ball from each site was removed from the water after 2-, 4-, and 6-day exposures. The tea balls, or their contents, were wrapped in absorbent tissue paper, then in absorbent toweling, the whole tagged and sent by regular mail to the Cincinnati laboratory. In most cases, water molds were recovered from these collections by the use of fresh hemp seeds.

On the basis of this experiment, tea balls were used for the remainder of the test series. They were allowed to remain in the sampling station for 3 to 5 days depending on work schedules of persons involved in placement and collection. Experience showed that the

TABLE V.—Fungus Species Found in North Branch, Potomac River, Maryland*

Station	*Achlya* sp.†	*Achlya americana*	*Achlya* sp. nr. *biserialis*	*Achlya flagellata*	*Achlya prolifera*	*Dictyuchus anomalus*	*Dictyuchus monosporus*	*Isoachlya*‡	*Olpidiopsis saprolegniae*	Olpidium (On *D. monosporus*)	*Pythium* sp.	*Saprolegnia* sp.†	*Saprolegnia* sp. nr. *dicina*	*Saprolegnia* sp. nr. *diosca*	*Saprolegnia fertilis* Group 19–18
6	X	X	X				X		X		X		X	X	X
7		X													X
9				X											
14	X	X					X				X	X			
16		X			X		X				X				
19		X			X	X	X	X		X	X				

* Direction of stream flow from Station 6 to Station 19.
† Non-sporulating.
‡ Non-fruiting.

shorter period of exposure was preferable.

After a colony had developed on hemp seed for at least one, sometimes two weeks, it was in a robust state actively producing many sporangia and sometimes oogonia with oospores. In this condition the relatively fresh cultures of saprolegniaceous fungi frequently were transported to other mycologists for identification or validation of identifications. Either cotton or folded laboratory tissue was moistened, a hemp seed with its colony placed on it, the tissue folded, the total wrapped in paper toweling, and numbered. When preparing cultures for shipment the primary wrapping material was damp enough so that it would not dry out in transit but not so wet that it would moisten the glue on the envelopes. The group of cultures wrapped in paper toweling could be wrapped again in wax paper or aluminum foil and this package could be placed in a box, culture tube mailing can, or envelope for mailing. On receipt of such material by cooperating specialists, to whom the collections were sent, the parcels were opened and planted again with fresh hemp seed. Usually, in the case of cultures wrapped in cotton, too many cotton fibers prevented immediate study, while those wrapped in tissue could be observed directly on being refloated in water.

Streams Sampled

To determine whether aquatic fungi can be found in grossly polluted waters, streams in the vicinity of Cincinnati were sought which would provide both clean reaches for control, and weakly to grossly polluted reaches for contrast.

Because there is a thorough back-

TABLE VI.—Fungus Species Found in Mill Creek, Cincinnati, and Hamilton County, Ohio*

Station†	*Achlya ambisexualis*	*Dictyuchus monosporus*	*Achlya* sp.‡	*Achlya oblongata*	*Achlya bisexualis*	*Aphanomyces parasiticus*	*Achlya dubia*	*Olpidiopsis fusiformis*
1	X	X	X	—	X	X	X	—
2	—	X	X	—	—	—	X	X
3	—	—	X	—	—	—	X	—
4	—	X	X	X	—	—	—	—
5	—	—	—	—	—	—	—	—

* Direction of stream flow from Station 1 to Station 5.

† General description of stations as follows:

1. Upper end of Sharon Lake, Sharon Woods County Park: Quiet water supporting surface growth of duck-weed and subsurface growth of water and shore plants. Lake stocked with fish. On a tributary of the East Branch of Mill Creek. Pollution sources: farmyards and occasional septic tank overflows.

2. Upper end of Winton Lake, Winton Woods County Park: Quiet water supporting heavy bloom of a blue-green alga in the fall. West Branch of Mill Creek. Pollution sources: area residents report extensive tapping of septic tank overflows into tributary streams.

3. Evendale, East Branch of Mill Creek: At crossing of State Route 126 (Bypass U. S. 50). Bottom muddy, no apparent surface or subsurface water plants. Pollution sources: wastes from several industries including chrome plating wastes. Probably some sanitary sewage.

4. Carthage, main stream of Mill Creek: Crossing of Springfield Road, Ohio Route 4. Within Cincinnati city limits. Stream flows over broad riffles and cement barrier formed from bridge abutment. Pollution sources: industrial wastes from additional types of industries including rocket motor plant and paper mills.

5. Winton Place, Cincinnati, main stream of Mill Creek: At crossing of Spring Grove Ave., below Ivorydale. Stream flows over broad riffle-pool area, has just fallen over small cement barrier and within a few feet will receive sewage and wastes. Pollution sources: probably some industrial wastes enter the stream above this point but much of this material is now diverted to interceptor sewers.

‡ Non-fruiting.

TABLE VII.—Water Quality Data, Mill Creek, 1957

(Based on Data Supplied by the City of Cincinnati)

Station	Coliform Count	DO (mg/l)	BOD (mg/l)	Water Temperature (°C)	Air Temperature (°C)	pH	Alkalinity (mg/l)	Turbidity (units)	Time of Observation
				(*a*) Mar. 20					
3	23,000	9.6	—	7.8	2.8	8.3	290	25	1030
4	9,300	8.0	—	10.0	2.9	8.1	250	25	845
5	93,000	6.9	100.0	11.1	6.1	7.0	200	45	1300
				(*b*) Apr. 17					
3	93,000	9.7	2.9	10.0	12.8	7.9	260	25	900
4	750,000	8.4	17.3	11.7	12.8	7.7	230	60	1015
5	930,000	6.2	346.4	12.2	11.1	7.4	210	200	1130
				(*c*) May 20					
3	230,000	7.7	3.8	15.0	12.8	7.6	130	900	845
4	430,000	7.3	7.8	15.5	13.9	7.7	130	900	945
5	430,000	6.4	16.0	16.1	15.0	7.4	120	1,000	1045
				(*d*) July 10					
3	43,000	4.7	1.8	22.0	21.0	7.6	310	35	845
4	23,000	6.7	1.9	22.0	22.0	7.6	190	25	900
5	93,000	4.2	5.0	24.0	24.0	7.4	200	25	1015
				(*e*) Aug. 22					
3	93,000	7.2	3.1	21.5	26.0	7.8	300	25	1040
4	23,000	7.3	6.8	21.0	21.5	7.4	190	25	955
5	930,000	0.1	93.0	24.0	30.0	6.7	230	49	1205

ground of biological knowledge on Lytle Creek, Clinton County, Ohio, resulting from intensive studies by others (3) (4), this stream was sampled twice. When baits were placed at the eight stations used in the present studies, it was assumed that conditions were essentially the same as those reported earlier. However, when the second set of baits was removed it was discovered that the Wilmington, Ohio, sewage treatment plant had added activated sludge treatment to the primary plant reported on in the earlier work. This change accounted for the cleaner characteristics of the stream.

The village of Batavia, Clermont County, Ohio, discharges primary treated sewage into the East Fork of the Little Miami River. Two sets of baits were exposed in the river, one above the town and one below this treatment plant.

Raw sewage from Williamsburg, Ohio, enters the East Fork of the Little Miami River more than eight miles above Batavia. This sewage flows slowly from sewers at three principal streets. Baits were placed in pairs at three points along the stream: in clean water above the outfall, and in what may be termed "recovery zone," below each of two outlets.

Paired nylon bag samplers were placed at three points along the Great Miami River at Hamilton, Butler County, Ohio. One pair was placed in a relatively clean, quiet impound-

ment above a paper mill, another was placed below the waste outlet of the mill, and the third below the lower outfall of the City of Hamilton where raw sewage flows into the river. No positive results were obtained from this test.

A stream survey was in progress on the North Branch of the Potomac River in October 1956, and tea ball samplers were exposed here also. Six stations were sampled and water quality data for them are given in Table I.

Finally, tea balls were exposed on two occasions in Mill Creek, Hamilton County, Ohio, at five different points in the drainage system, including two relatively clean recreation lakes in County parks near the headwaters, as well as in highly polluted areas downstream. Exposures were made in September 1957 and June 1958.

Although referable to a somewhat different period than represented by the data from Mill Creek in Table II the water quality data in Table VII, which were made available by the City of Cincinnati, show the general character of three of the five stations. Such water quality data serve to complete the information necessary for full evaluation of a stream.

Problems experienced in the bait program were largely centered about curiosity of persons who frequented places where baits were exposed. However, such curiosity was expressed less frequently than expected, and baits were lost only on Lytle Creek and the Great Miami River.

Species of fungi found on the several surveys are listed in Tables II, III, IV, V, and VI for each of the streams studied. Where more than one bait was used, the same species of water mold was recovered on one or more of the different baits.

Discussion

When the aquatic fungi listed in Tables II, III, IV, V, and VI were studied in relation to the water quality conditions described, it becomes evident that there is little, if any, correlation between pollution aspects of habitat and fungus occurrence. Aquatic fungus populations in Lytle Creek at the times of sampling were relatively uniform in contrast to Harvey's findings indicating that the stream may have been relatively clean. No particular influence on water mold populations was noted in the East Fork of the Little Miami River either by the effluent from the sewage treatment plant at Batavia, or the raw sewage at Williamsburg. If any relation between pollution and the occurrence of water molds can be noted in the Potomac River, it is that aquatic fungi do not grow well in clean water. The downstream decline in occurrence of aquatic fungi in Mill Creek may be related to increasingly heavy loads of industrial wastes which may contain substances toxic to certain types of life.

In both the Potomac River and Mill Creek, accuracy and ease of sampling were affected by unexpected high water following rain which flushed out pools and transported planktonic life to points downstream. This had the effect of making the pools and the streams appear temporarily clean. The actively swimming zoospores of aquatic fungi are planktonic and thus could easily have been accidentally trapped by baits in other parts of the stream.

Relationships of aquatic fungi to dissolved oxygen and biochemical oxygen demand of a stream are as yet imperfectly understood. It is assumed that such fungi require relatively high levels of dissolved oxygen in the water although it is known that certain water molds are microaerophilic. Since no particular distribution pattern has been observed in relation to polluted reaches of several streams, no statements can be made in respect to oxygen requirements of the fungi listed herein.

An attempt was made to obtain chitrids that habitually grow on pollen by the use of goldenrod and aster pollens in the autumn and Douglas fir pollen in the early summer. However,

possibly because of the short period of time used for exposure, 5 and 3 days, respectively, no such fungi were obtained in the Mill Creek basin.

Summary and Conclusions

A number of relatively common aquatic fungi have been isolated from pools in areas of streams that receive domestic sewage and industrial wastes. Techniques of bait exposure are easily applied, but results of exposures made to date indicate that additional information gained in this way has little value in determining the degree of pollution of a stream. In part, this may be due to having used too short an exposure time to obtain certain types of organisms; in part, it is due to the scouring of flash floods from unpredictable precipitation. No aquatic fungi have been found with restricted distribution to polluted reaches of streams, and similarly no aquatic fungi have been found which are restricted to so-called clean water portions of streams. It is quite possible that more intensive study of the technique of using special baits, sampling periods, and altering other variables may yield a procedure of greater diagnostic value.

When making surveys of any type of body of water for aquatic fungi maintenance of a record of water quality data for sites at which aquatic fungi are found is recommended.

Acknowledgments

During the Lytle Creek phase of the study, Fred T. Wolf, Vanderbilt University, assisted with identifications. Later, Terry W. Johnson, Duke University, was helpful. Douglas fir pollen used in one set of exposures was obtained at Troy, Idaho, by R. F. Daubenmire in May 1958. George Matsuura helped in the laboratory with culture transfers and pure culture techniques.

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SANITARY ENGINEERING MANPOWER

The Public Health Service has recently issued a publication entitled "Sanitary Engineering Manpower," which reports pertinent information about a representative group of sanitary engineers in the United States.

The original data were gathered in cooperation with the National Science Foundation's Scientific and Engineering Manpower unit. The data represent a collective picture of the age, education, professional experience, years of service, kind and type of employment, income, and related characteristics of approximately 4,000 sanitary engineers, a group which, in turn, represents almost two-thirds of the total estimated number of such engineers in the country.

This is Public Health Service Publication No. 703 and is listed for sale at 25 cents by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

DISPOSAL OF RADIOACTIVE LIQUIDS FROM NUCLEAR POWERED SHIPS*

By James M. Smith, Jr.

Radiological Engineer, Atomic Power Equipment Department, General Electric Company, San Jose, Calif.

General environmental problems from use of commercial nuclear powered ships are just beginning. The nuclear powered ship ***N.S. Savannah*** is being constructed, and several other applications of reactor systems for maritime use are in study and design stages.

Many popular and semitechnical articles appearing in connection with waste disposal problems from nuclear powered ships imply that the total fission product inventory of the reactor will be available for disposal to the sea, thus causing a serious problem. This is hardly the case, since in any application, a very high fraction of the fission product inventory of maritime reactor fuel will remain with the fuel. The proper disposition of most of the fission products will be a factor in connection with the operation of the fuel reprocessing separations plants, and thus, will be no different than the same problem in processing fuel from AEC production facilities and land-based commercial nuclear power applications.

Thus, the operation of a nuclear powered ship will involve the production of relatively small quantities of corrosion product and fission product wastes which must be handled in a safe manner. The general choice of safe handling of these limited quantities of wastes lies between (a) complete retention aboard ship, with subsequent relatively expensive transfer to dockside storage or transportation facilities, for typical land-based processing or storage; or (b) a reasonable use of the extensive volumes of the oceans of the world, to receive these small quantities of radioactive wastes, if such use of the natural environment can be done with a high degree of safety. Both economics and common sense indicate that this latter avenue should be thoroughly explored for feasibility before transfer to facilities on land should be seriously considered.

Types of Reactors Considered

At this time the early applications of nuclear power for marine propulsion consider the use of either the pressurized water or the boiling water reactor system. Therefore, this paper will limit its consideration to water-cooled and moderated reactor systems. Regardless of the specific water type system employed, radioactive waste problems are generally similar.

Wastes from Nuclear Powered Ships

Solid Wastes

The principal solid waste from these types of reactors, which might also be high in radioactivity content, has its origin in demineralizers which would be used at several points in the reactor and steam systems. Water reactors usually have a reactor cleanup demineralizer system. This system continuously removes a small portion of the primary water recirculating

* Presented at the Fifth Nuclear Engineering and Science Conference; Cleveland, Ohio; Apr. 5–10, 1959.

through the reactor core and passes it through filters and/or demineralizers for removal of both suspended and dissolved solids of both radioactive and nonradioactive species. The purpose of this system is to maintain the high degree of purity of reactor water required. The resin charge in a typical system might consist of 1 to 10 cu ft of mixed anionic and cationic resins which might require replacement every two to three months. At the termination of use of a batch of such resin, it may have collected approximately 100 c of radioactive corrosion products of elements dependent on the materials of construction of the reactor water system and reactor core surfaces. In the event that some reactor fuel had become defective during this operating period, additional quantities of radioactive fission products may also be fixed on the resin. The quantity of such fission product activity is most difficult to predict, as it is a function of the number and severity of fuel element failures. In a typical pessimistic case, 100 to 1,000 c of the longer-lived fission products might be included in one resin charge. About 100 gal of water would be required to flush a batch of resin out of its container for disposal either directly to the sea or to temporary storage aboard ship.

Similar resins are employed in some reactor systems to purify condensate prior to return of such feedwater to the reactor system. The volume of resin in such a system might be of the order of 30 cu ft and such resin would require replacement or regeneration every several weeks. It is estimated that this resin, or solutions used for regeneration of the resin batch, might contain radioactivity composed of one curie of assorted corrosion and fission products.

Liquid Wastes

The above-mentioned condensate demineralizer regeneration solution is one of the chronic liquid waste problems associated with certain types of reactor systems. Such solutions could be disposed of either directly to the sea, or could be held in waste collection tanks for ultimate disposal.

In a water-type reactor and its associated steam systems, some leakage of relatively high purity water from the systems must be anticipated. The volume of such wastes might be conservatively estimated as amounting to 100 gpd, but the expected concentration of long-lived radioisotopes would be exceedingly low under normal conditions.

Number of Nuclear Powered Ships

It is suggested that the estimated number of nuclear ships of the 60 million watts reactor heat rate class may be a maximum of 100 available in the world, of which not more than 10 are in one locality or one harbor at a time.

The proposed number of 100 available in the world is based on the fact that there are currently less than 100 merchant ships in the world with displacements of greater than 20,000 tons. The proposed assumption, therefore, includes the thought that the large vessel merchant marine of the world is doubled in size, and that all of the additional capacity is nuclear powered. The probability that 1,000 nuclear powered ships of this size might exist in the next several decades is believed to be extremely small. From these several points of view, the assumption of 100 nuclear powered ships appears to be sufficiently conservative for this purpose.

The probability of any high percentage of the total nuclear powered ships assumed to be available in the world being in one harbor or in one locality at any one time, is also very slight. Therefore, it is suggested that not more than 10 of the available ships be considered as being in one locality at a time. This is considered to be

highly conservative as it is far more likely that only one or two of the assumed 100 ships available will be in one harbor at a time.

These conservative estimates permit the consideration that a significant number of nuclear powered military vessels also may be present in the world. It is suggested that the above basis is adequate as long as the total of nuclear ships is less than, say, 300.

Recent Study of the Problem

In 1958 the National Academy of Sciences National Research Council Committee on the Effects of Atomic Radiation on Oceanography and Fisheries appointed a study group to consider the general waste disposal problem at sea from nuclear powered ships. In the final report of this committee the general approach was to estimate the amounts and characteristics of wastes expected from the assumed number of such operating systems; to consider disposal of the wastes produced in harbors and estuaries, on the continental shelf, and in the open sea; dispersion of the wastes within the various subdivisions of the marine environment; and possible hazards to man, with primary regard to the food chain relationships of marine organisms to man.

Proposed Disposal Criteria

Harbors and Coastal Waters

It was suggested that no contaminated demineralizer resins be discharged in harbors, estuaries, or in coastal waters within one mile of the shore, and that liquid radioactive solutions should be discharged in such areas only if the concentrations of the contained radioisotopes are less than currently accepted permissible drinking water limits. This latter suggestion is not on the basis that such waters will be used for drinking, but merely that the use of such conveniently available limits provides conservative protection in the food chain relationship problem.

Coastal Waters

In the general area of coastal waters between 1 and 12 miles from the coastline, it was suggested that solid wastes should not be introduced because of the possibility of accidental recovery. For liquid solutions, depending on the frequency of discharge and the radioisotopic content, individual discharges of up to the order of 1,000 c appear permissible.

Outer Continental Shelf

In the outer continental shelf area, ranging from 12 miles offshore to the 200-fathom depth continental shelf, it was suggested that contaminated resins should not be discharged into known fishing areas of this region. In nonfishing regions, limited disposal of contaminated resins appears feasible. Also, in this general area, no restriction appears necessary on the discharge of liquid solutions, assuming that the composition and quantity of radioisotopes is about that expected from the water reactor systems.

The Open Sea

No restriction appears necessary in the discharge of radioactive waste solutions in the open sea. For contaminated resins, it was suggested that these may be discharged into this area with a 500-c limit on any single discharge, with restrictions applied in the regions of the larger oceanic fishing areas.

This is a very brief and over-simplified summary of the suggestions made by the study group, and reference should be made to the full report, which is available as Publication No. 658, National Academy of Sciences–National Research Council, Washington, D. C. (1959).

Design for Such Criteria

It is generally suggested that where the choice is possible, disposals be made in the regions farthest from land. As the schedule of need for disposal can be reasonably predicted during the operation of a ship, it would seem that proper scheduling of disposals could provide important additional protection in reducing contamination of inshore waters over that postulated by the recommended criteria. To permit latitude in the operating decision as to when or where wastes should be released, it will be appropriate for nuclear powered ship designs to include a reasonable capacity for temporary waste storage. This relatively small volume storage will also provide the opportunity for sampling and/or monitoring the waste batch so that its total activity and radioisotopic content may be determined to the extent necessary.

To provide even further protection, the inclusion of a small capacity waste evaporator would provide the opportunity for safe handling of any unusually high activity waste which might exceed the generally liberal disposal criteria which have been suggested. The condensate from such an evaporation process should contain only low concentrations of radioisotopes, and thus, in most cases would be suitable for direct disposal in any of the regions considered.

Present Criteria

The only present operating criteria in use are those of a Bureau of Ships Instruction on disposal of radioactive effluents from U. S. Naval nuclear powered ships. This is available as Buships Instruction 9890.5, Department of the Navy, Bureau of Ships, Washington 25, D. C. (12 May 1958). With regard to spent demineralizer resins, these may be disposed of overboard when the ship is more than 12 miles from shore and when the ship is in motion, other ships are not within 3 miles, and the ship is in non-fishing areas. With regard to liquid waste solutions, Naval ships may discharge such wastes when more than 12 miles from shore without restriction. When within 12 miles, or when within harbors, such liquids may be discharged, with certain activity level restrictions.

A review indicates that these existing regulations are not significantly at variance with the recent recommendations of the study group.

Gaseous Wastes

In passing, it may be noted that disposal of radioactive gaseous wastes from water-type reactor nuclear powered ships should provide little problem with regard to environmental radiation exposures. Retention of the off-gases from the reactor or condenser systems for a period of a day or two in temporary tank storage provides significant reduction by radioactive decay in the quantities of activity which may be available for discharge to atmosphere. While a tall stack is hardly appropriate aboard ship, the release of such gases with the condenser cooling water will provide a method of safe disposal with regard to possible exposure of personnel aboard the ship. The only restriction during periods of such radiogas release would appear to be that the ship should change its course temporarily if necessary, to avoid motion in the direction of the prevailing wind.

Conclusions

The recent study of the problem of disposal of wastes from nuclear powered ships indicates that only limited facilities must be installed to provide essentially complete protection of the ship's marine environment. The frequency and composition of the wastes expected from water-type reactor systems are such that in most cases intelligent use of the sea for direct disposal can be made.

THE OPERATOR'S CORNER

A DENSITY METER TO CONTROL SLUDGE PUMPING *

By Walter E. Garrison and Carl A. Nagel

Respectively, Division Engineer, and Superintendent of Sewage Treatment, Los Angeles County Sanitation Districts, Los Angeles, Calif.

One of the more important duties of a sewage treatment plant operator is to see that only the thickest sludge is transferred to the digester. This can be done only if pump controls are sensitive to sludge density. The ideal pumping system would be one which responds automatically to variations in the solids content of the sludge.

The system described here is the first one known to the authors wherein the density of raw sludge is used to control automatically the sludge pumping schedule. Operation has proved to be completely satisfactory and the County Sanitation Districts are now converting the control of all raw sludge pumps to this system.

Benefits from Pumping Thick Sludge

As a preliminary to a description of the various existing methods of pump control, it may be well to review briefly the benefits derived from pumping thick sludge. The first and most obvious is the saving of digester capacity. If excessive quantities of water are pumped to the digester, the detention time is reduced. Under such circumstances, sludge is only partially digested and the impression may be created that the digester capacity needs to be increased. Digesters represent approximately 25 to 30 per cent of plant construction cost, so a saving in digester capacity means a considerable saving in over-all construction cost.

Providing ample boiler capacity to maintain unvarying temperatures is of even greater importance in cold climates than in the temperate Southwest. If the average solids content of sludge pumped to the digesters is on the order of 4 per cent and if this can be increased to 6 per cent, a saving in boiler capacity of 33 per cent can be realized. This represents a saving not only in first cost but also a very significant saving in operating cost, even where boilers utilize digester gas.

If the raw sludge is carefully controlled as it leaves the sludge hoppers of the sedimentation tanks, it is possible to utilize the hoppers for compression of solids in the sludge. This procedure would eliminate both the need for sludge thickeners with their attendant odor problem and the problem of returning supernatant to the plant influent. Actually, the main reason for using sludge thickeners in some sewage treatment plants is because precise control over sludge density has not been obtainable with any of the

* Presented at the 31st Annual Conference, California Sewage and Industrial Wastes Assn.; Long Beach, Calif.; Apr. 29–May 2, 1959.

existing systems of sludge pump control.

If the basic objective in processing sludge after digestion is the elimination of excess water, it seems clear that more attention should be given to the pumping of thick sludge to the digestion system. This is true regardless of the method of dewatering used.

Through the development of a dependable and rugged system of sludge pumping, the sludge-handling system can be completely enclosed, without open tanks or observation boxes. This means that odor problems can be eliminated. And in the County Sanitation Districts this is a major consideration because the sewage arrives at the treatment plant in a septic condition.

If the sludge quantity is appreciably reduced, smaller pumps will serve the same number of sedimentation tanks, and with smaller power requirements. In addition, if the system is dependable enough, it is possible to use one pump for several tanks, thus realizing a savings in piping and pumps—a saving that would follow right through the digestion system.

Another advantage envisioned is the reduction of plant operating personnel brought about by the use of automatic controls.

Methods of Sludge Pump Control

Visual Observation

In small sewage treatment plants probably the most common type of density control consists of visually observing the sludge as it is drawn to an observation well prior to pumping. This kind of system requires the operator to be present during the pumping process. With this system reasonably good control can be obtained. Unfortunately, each sludge withdrawal must be followed by a washing of the observation well to minimize the accumulation of dry sludge. Also, the success of this method is directly related to the operator's estimate of the percentage of solids in the raw sludge.

The use of sight glasses in the sludge lines has certainly been of some help in density control, but here again the operator has to estimate the solids content by making a visual observation. It has been the authors' observation that where the collection system is short and the sewage quite fresh, the sight glass is fairly satisfactory; however, in larger treatment plants where the sewage arrives in a septic condition it is sometimes difficult to differentiate between the sludge and sewage because both have a black opaque appearance.

In those plants where an excess of sludge can be pumped from the sedimentation tank hopper, the use of a sight glass in conjunction with automatic timing has proved quite satisfactory. This situation obtains in three of the treatment plants operated by the County Sanitation Districts. Here the plants are operated for water reclamation purposes and the raw sludge is discharged to an adjacent sewer and transported to a large central treatment plant for processing. In a system such as this it is important only that all sludge be removed, thus control of the solids content is not critical.

Another system which could be used for sludge pump control utilizes continuous sampling from the pump lines whenever sludge is withdrawn. A slop sink is provided through which the samples are returned to the sewage flow. This system provides good control but is costly in terms of operator time and it is messy.

Timing Method

In the larger treatment plants the use of programmed timers to control pumping is common. This system, once adjusted, would be perfectly adequate providing that the sludge pumps deliver a constant quantity of flow under all head conditions. This criterion could be met only by using positive displacement pumps since the inherent

characteristics of a centrifugal pump are such that the discharge varies with the head. Here one must also balance the advantages and disadvantages of these two general types of equipment. Another weakness of the time-control method is that there is no way to compensate automatically for the variable

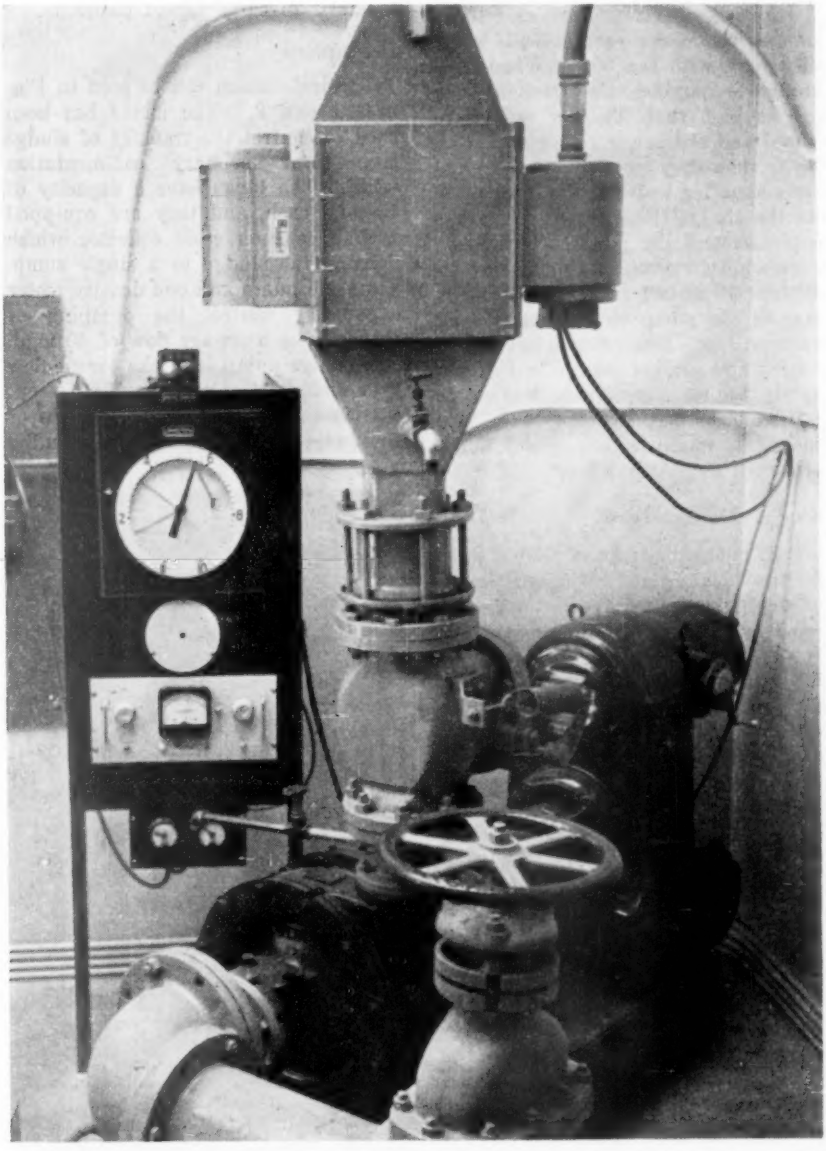

FIGURE 1.—Sludge density meter is housed in vertical transition section in top center; control panel is on left.

rate of sludge accumulation which is caused by the inconstant composition of sewage.

Electric Current Sensing

In the operation of centrifugal pumps, the power requirements normally vary with the flow. When thick sludge is handled, the friction losses are so high that the flow rate is reduced and the power requirements are lower than they would be if the pump were handling water at the same speed. As the sludge thins out, the flow rate increases and the power requirements go up. An attempt was made by the District to install current-sensitive relays in the pump circuits to take advantage of this characteristic of centrifugal sludge pumps. Unfortunately, the resulting system was not dependable because factors other than the solids concentration caused fluctuations in the current flow.

Sludge Thickeners

Still another system of sludge transfer provides for continuous withdrawal of sludge to a thickener. Here the removal of thickened sludge from the bottom of the thickener tank can be carefully controlled and the amount of labor for a given quantity of sludge can be minimized. This system, however, requires a substantial capital investment, and unless the thickeners are covered or housed, an odor problem may result. The return of the thickener overflow, although not as difficult to handle as the supernatant from digesters, can be rather troublesome.

Radioactive Density Meter

Initial investigation into the use of a radioactive density meter for sludge pump control was started by the Districts in July 1949. This led to the purchase of the necessary components in the latter part of 1958. The meter and controls were installed at the Districts' Joint Disposal Plant during March 1959. Obviously, the new system has not been in operation long enough to develop basic data for inclusion in this report; however, the results have been encouraging enough to make an early report desirable.

Description

The installation can be seen in Figures 1 and 2. The meter has been used to control the transfer of sludge from four primary sedimentation tanks. The tanks have a capacity of 10 mgd each, and they are equipped with a common cross collector which delivers the sludge to a single sump. Thus one pump and one density meter adequately control the pumping of sludge from a sewage flow of 40 mgd. The sludge pump is of the torque-flow type and its relatively trouble-free operation is important to the success of the sludge-handling system. A standby

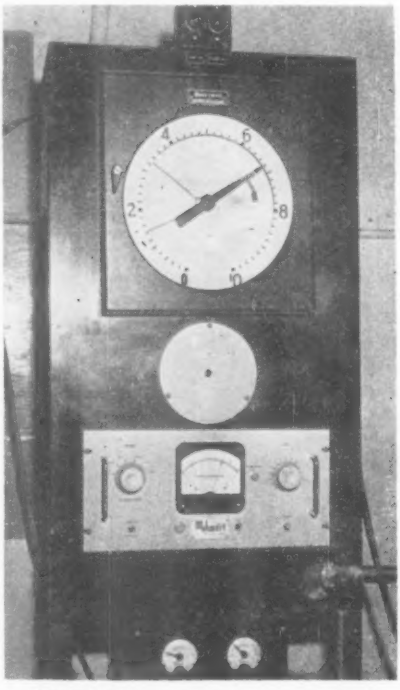

FIGURE 2.—Closeup of control panel.

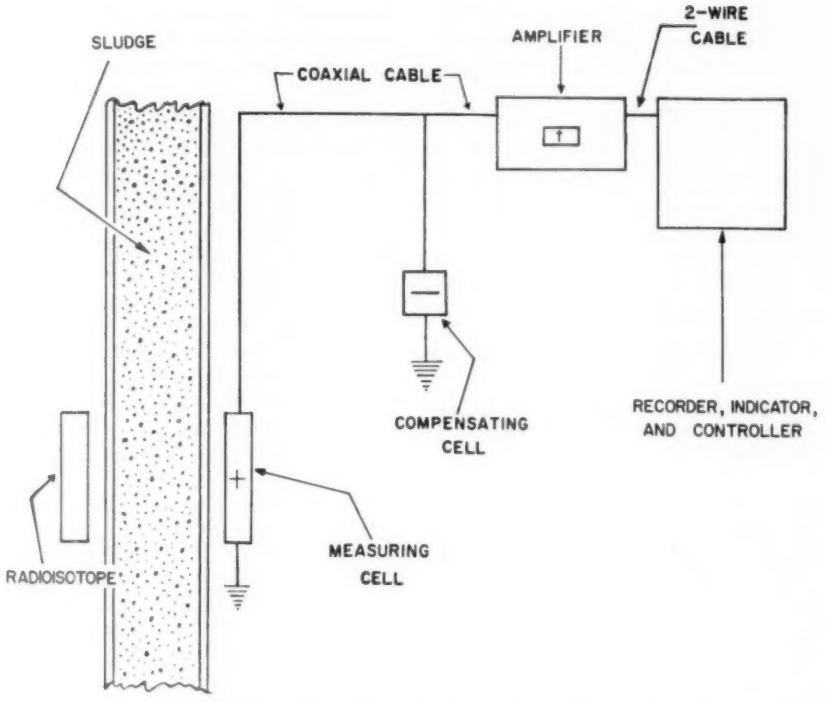

FIGURE 3.—Components of density metering system.

pump is provided to relieve any temporary plugging which might occur.

The meter (Figure 3) functions as follows: A radioactive source of cesium-137 in a shielded container is bolted to one side of a special transition section in the pump discharge piping. The gamma rays released from this radioisotope are measured on the opposite side of the pipe section by a cell containing two electrodes which are separated by argon gas. Since the penetration of the gamma rays through the pipe section is a function of the mass of material, the amount of radiation penetrating to the measuring cell varies with the solids content of the sludge. The gamma rays ionize the argon gas in the measuring cell resulting in the generation of an electrical current which flows in a carefully shielded circuit. The amount of current flowing in this circuit is a function of the solids concentration of the sludge. A zero-calibration of the instrument is made by using a shielded source of radium to generate a balancing current of opposite polarity. When the current flow from both sources is in balance the net result is a zero output of current to the amplifier. The amplifier, as the name implies, amplifies the small variable current flow and sends the amplified signal to a recorder which is calibrated directly in per cent solids. In this particular installation the solids range is from 0 to 10 per cent.

Calibration

The initial calibration of the instrument was accomplished by first placing fresh water in the transition section to determine the zero reading. The

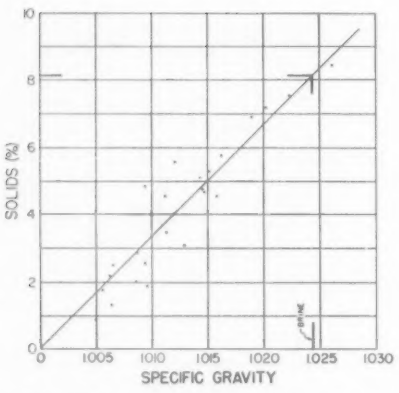

FIGURE 4.—Relationship between specific gravity and the solids concentration in raw sludge.

fresh water was then replaced with salt water having a specific gravity of 1.0245 which corresponds to raw sludge with a solids content of 8.2 per cent. The approximate relationship between specific gravity and solids concentration is shown in Figure 4. This plot is a summary of various data collected at the Joint Disposal Plant.

In the event that an accumulation of grease develops in the transition section which would affect the calibration, the zero-suppression from the radium source can be varied by a simple adjustment with a screwdriver.

The installation is designed to limit the maximum radiation to less than 6.25 mr/hr at a distance of 10 in. from the source. Actual measurements with a survey meter indicate that the radiation intensity is only slightly greater than half of this amount. The allowable radiation intensity limit for the legs, arms, head or neck of an operator is 1,500 mr/wk and 300 mr/wk for the torso. To receive an exposure to 300 mr/wk, an operator would have to work 48 hr/wk at a distance of 10 in. from the source. The installation is completely safe in this respect and thousands of such instruments have already been installed in various industrial plants throughout the country. Licensing by the Atomic Energy Commission and routine inspection are required to assure absolute safety.

Method of Operation

The operation of the meter and controls is as follows: Assuming the sludge pump is in operation and pumping a sludge containing more than 6 per cent of solids, the pump will continue to operate until the solids concentration drops to a predetermined level. After field testing at various values, the low level was set at 5.2 per cent. When the sludge solids drop to this level, mercoid switches on the recorder are tripped which result in (a) a shutdown of the sludge pump, and (b) a startup of Timer 1. Timer 1 is adjustable over a 60-min range and its purpose is to keep the pump in the "off" position for a preset interval regardless of the solids concentration of the sludge in the pipe section of the meter. When Timer 1 reaches the end of the "off" cycle it (a) starts the sludge pump and (b) switches the control of the sludge pump to Timer 2 which can be referred to as a time-delay instrument. This second timer maintains the pump in the "on" position regardless of the solids concentration in the transition section, and it is adjustable over a 5-min range. The purpose of Timer 2 is to ensure that a new supply of raw sludge has reached the metering section and that the control of the pump is not being accomplished by residual sludge from the previous cycle. When Timer 2 reaches the end of its cycle, it switches control of the pump to the recorder and the pump continues to run until the sludge again thins down to the preset low level.

In a system such as this, the pump cycle is not fixed, for each sequence of operation is actuated only after completion of the previous operation. If heavy sludges are being handled, the pump could run for hours if necessary. In actual operation, Timer 1 has been

adjusted for varying times ranging from 15 to 30 min. Timer 2 has been set at approximately 1.25 min. The delay time was determined by observing the movement of the indicator arm on the recorder chart. It allows ample time for a new supply of sludge to reach the transition section.

When the original installation was designed, there was some fear that grease would accumulate on the inside of the transition section; however, after about four weeks of operation, the grease buildup was so minor that adjustment of the compensating cell was unnecessary. In the event of grease accumulations, steam can be injected directly into the pipe since the entire installation can withstand fluid temperatures as high as 400°F. Correlation of the readings on the recorder chart with laboratory analyses shows that the meter has been accurate to 0.5-per cent solids by weight. In checking the calibration, it is extremely difficult to state whether the sludge samples are representative of the sludge in the entire cross-section of the pipe since the sample necessarily must be withdrawn from the periphery of the 6-in. pipe.

A detailed program of in-plant training was undertaken to inform personnel about the nature of the new installation. No problems have developed because of needless fears.

Observations on Sludge Behavior

Operating results indicate that the only limitation on the solids concentration pumped is imposed by the ability of the sludge pump to handle the thicker material. By lengthening the off-time of the pump more sludge is accumulated in the sludge hopper and more compression occurs up to some maximum yet to be determined.

Maximum holding time in the hopper may also be limited by possible bulking of the sludge, although this has not yet occurred. The present settings of Timer 1 at 20 min and Timer 2 at 1.25 min have resulted in virtually trouble-free operation. The pump cycles from 50 to 70 times per day as can be noted by reference to the control chart in Figure 5. The shaded area in Figure 5 represents the portion of time the pumps are in operation.

The variation in sewage flow was compared with the corresponding variation in solids concentration and an interesting relationship was immediately apparent. As the sludge varied between approximately 6- and 10-per

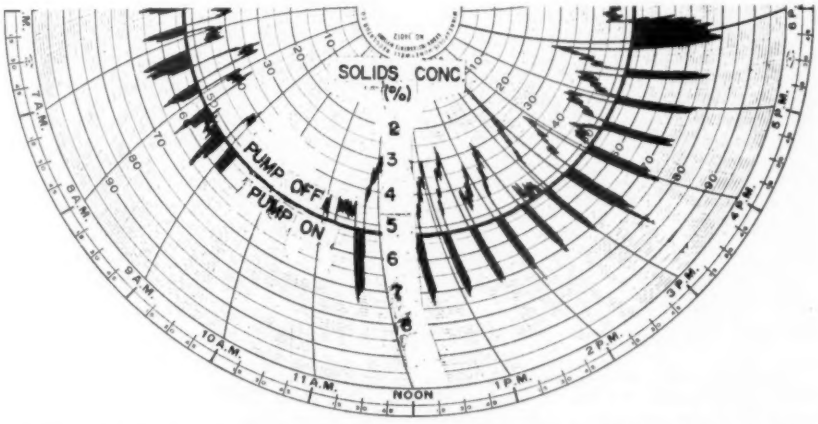

FIGURE 5.—Control chart. Pump stops when solids concentration drops to 5.2 per cent.

cent solids, the sewage flow varied between 150 and 250 mgd. Inasmuch as no grit removal system is provided at the Districts' Joint Disposal Plant, it would seem entirely probable that during peak flow proportionally larger quantities of grit are moving to the treatment works. During one 24-hour period, the volatile solids portion of the total solids in the raw sludge varied from 78 per cent at minimum flow to 70 per cent during maximum flow.

The instrumentation is well designed and properly damped to avoid rapid oscillations. During initial startup, the sedimentation tanks were not pumped for extended periods and frequently it was possible to watch the density meter and observe the effect on the chart as each cross-collector flight carried a new supply of sludge to the sludge hopper. Sludges having more than 10-per cent solids were handled on numerous occasions during the startup period.

One may note from Figure 5 that the solids in the sludge stay at a rather high level during the pumping period and the breakthrough, when it comes, is abrupt. This characteristic would probably vary with the type of sludge, the pumping rate, and the hopper depth.

Other Uses of the Density Meter

If subsequent observation of the test installation indicates that the stability and accuracy are within tolerable limits, it is entirely possible that a magnetic flow meter could be placed in series with the density meter and the measurements from both instruments integrated to record on a common chart the pounds of dry solids pumped.

Two more density meters will be installed * at the Districts' plant. In one case the meter will control automatically the pumping from four hoppers rather than a single hopper. This will be done by successively pumping from each hopper in the series and then cutting the pump off for some preset period before repeating the cycle. In the other case, the density meter will control the sludge transfer from six hoppers.

The number of hoppers which can be controlled by a single meter is dictated primarily by the rate of sludge accumulation during peak flows and the sludge-pumping capacity. In existing plants, the layout of sedimentation tanks and suction lines would govern the location and number of density meters required.

Results to date indicate that a meter could be used for the recording of the solids concentration in digested sludge. In particular, the Sanitation Districts sell digested sludge to a fertilizer manufacturer and more accurate determination of the pounds of dry solids pumped would be desirable. Before an installation of this type could be designed, it would be necessary to determine the relationship between the solids content and specific gravity of digested sludge since it is recognized that it will differ from the raw-sludge relationship. Also, the presence of entrained gas makes this application questionable.

In plants with existing sludge thickeners, the meter could be used for controlled pumping of the underflow.

Conclusions

There has been a great improvement in raw-sludge pumping since the automatic density-control system was placed in operation. The maximum concentration of solids that can be pumped to the digesters appears to be governed more by the capabilities of the pump than by the sensing and switching properties possessed by the control system.

* Since this paper was prepared both meters have been installed, and the installations described later are operating successfully.

Acknowledgment

Mr. C. R. Compton is Chief Engineer and General Manager of the Los Angeles County Sanitation Districts. The design and installation of the density meter were done under the supervision of Mr. John D. Parkhurst, Assistant Chief Engineer, Los Angeles County Sanitation Districts. The basic component of the meter was manufactured by the Ohmart Corporation, Cincinnati, Ohio.

TRACKING INDUSTRIAL WASTES *

By Doris Voshel

Chief Chemist, Sewage Treatment Plant, Grand Rapids, Mich.

For an extended period of its history Grand Rapids, Mich., has been a furniture city. Because of its location on the lower reaches of Grand River, it became a center of the logging industry. As the saw mills and lumber yards developed along the river banks, the manufacturing of furniture continued to grow. Grand Rapids' population in 1900 was 88,000 and today the metropolitan area includes approximately 350,000 people.

In 1929 a primary sewage treatment plant with separate digestion was built. Not long after the plant was put into operation, Grand Rapids began to experience industrial diversification. Automobile manufacturers and their suppliers added industrial balance, and furniture makers were beginning to make the transition from wood to metal office furniture. Now among the existing 780 industries are more than 30 metal-plating plants plus tanneries and other metal-processing plants most of which discharge their wastewater to the sanitary sewer system.

Eleven years ago it was evident the time had arrived for Grand Rapids to expand and improve its sewage treatment facilities. This program was completed in the early part of 1959.

Experience gained in operating the expanded facilities during the last three years has underscored the fact that unless reasonable control is exercised over the quality of industrial wastewaters entering the municipal collection system, difficult treatment problems are likely to be encountered.

Method of Survey

Faced with operating problems suspected to be caused by toxic metal ions, it was decided that an industrial waste survey should be made. In this connection the assistance of the city engineer's department was solicited for seasonal staff reinforcements.

Questionnaire

The survey was begun by sending a questionnaire to all 780 industries. This was done over the signature of both the city engineer and the superintendent of the treatment plant. The questionnaire was designed to facilitate the reporting of necessary basic information with an eye toward the avoidance of critical responses. Remarkably, all of the firms replied. On the basis of the replies, the industries were classified into one of two categories: (a) those that had no waste problem; and (b) those that might or did have a problem. The entire questionnaire operation was completed during June.

* Presented at the 33rd Annual Conference, Michigan Sewage and Industrial Wastes Assn.; Charlevoix, Mich.; June 23–25, 1958.

Field Sampling

Concurrent with questionnaire processing, the survey crew, working from an up-to-date map of the system, began sampling; first by testing the main trunk lines, and then working upstream until negative results were obtained (Figures 1 and 2). In this way each section of the city was screened off. The results were recorded on a map with colored pins, a concentration of 0.5 mg/l or greater of either cyanide, copper, nickel or hexavalent chromium was sufficient for a red pin. Those sampling locations where negligible amounts were found were identified with a white pin. The next step was to localize the source of the waste by investigating the laterals leading to the critical trunk lines. Finally, with the aid of the information in the questionnaire, about 30 industries were located which were potentially troublesome.

During July, either the factory sewer or the street sewer, above and below the factory sewer, was sampled. Sampling at any one location continued over 24 hr with samples being collected at 1-hr intervals in an attempt to establish the variation in waste concentrations. This sampling procedure was repeated several times at each plant site.

Most of August was devoted to sampling each industry once a day, but at various times, to determine the frequency of slug discharges. All of the results of the July and August activities concerning individual industries were recorded and transferred to separate folders for each industry. They are available for inspection at the sewage treatment plant.

The influent and effluent flow at the sewage plant was tested at ½-hr intervals for a period of two weeks from 6:30 AM to 9:30 PM in an effort to: (a) uncover a pattern for the appearance of high concentrations of toxic components; (b) observe and follow a shock load as it entered the plant;

FIGURE 1.—Sampling equipment. Each sampling car was furnished with: a pick; traffic cones and a warning sign; a cone-shaped, weighted bucket; rubber gloves; pint-sized paper containers with covers; wood carrying boxes; and a hand pump.

FIGURE 2.—Sample collection. In 10 of the 30 sampling locations a hand pump was used to collect samples.

and (c) determine how effective each unit of the plant was in removing the ions.

Special efforts were made to determine if shock loads originated on weekend cleanups. Sampling took place on several Friday nights and some Saturdays. In general, it was found that metals and cyanide were coming to the plant on an almost continuous basis with the exception that none came on Sunday, and on Friday nights and Saturday mornings there was a somewhat heavier concentration.

Organization

The crew for the operation consisted of six men. Each day the group split into three teams of two men each. Two men ran the laboratory tests (Figure 3), two men sampled, and the last two men spent part of their time sampling and part scouting for industries and attempting to locate the sources of "positive" pins on the map

FIGURE 3.—Plant laboratory. All laboratory tests were performed as outlined in the Michigan Sewage Works Operators' Manual.

of the city. Four of the six men were qualified to do laboratory work and two men were permanent samplers. Each day two of the laboratory-qualified men accompanied the samplers. Thus two sampling crews were formed, each consisting of one permanent sampler and one laboratory man. Each laboratory man spent one day in the laboratory and one day in the field. The sampling crews reported every noon and every evening with the samples they had collected in the half-day period. During a 50-day working period, 1,892 samples were collected and analyzed making a total of 7,568 individual tests. It should be noted that the tests for copper and nickel were considerably more time-consuming than were the tests for hexavalent chromium and cyanide. Limiting the testing to these latter constituents could certainly double the output of the laboratory.

As mentioned earlier, one of the sampling crews spent a considerable amount of time scouting and locating industries. The crew also spent time searching the official files to locate the laterals of specific industries. Thus their sample intake was considerably less than the second team which confined its interest only to collecting samples. On a typical day, the crew confined only to sampling would bring in about 35 samples, the other crew about 15. Of course, the daily average of samples was less than the implied total because of organization time, bad weather, etc.

With the opening of the college year the survey came to an end, but the industrial waste chemist, who is a permanent member of the treatment plant staff, continued to sample the locations where significant concentrations of metallic ions were found.

City-Industry

After the completion of the survey, a meeting was held with industry representatives to explain the results in terms of treatment plant operations. The records for each plant were made available and each company was asked to review their operations keeping in mind that this was as much their problem as it was the City's. The general nature of requirements of the Grand Rapids sewage ordinance was discussed and the following limitations on deleterious wastes discharged to the sewer were recommended: (a) hexavalent chromium—4 mg/l; (b) cyanide—5 mg/l; (c) nickel—5 to 8 mg/l; and (d) copper—5 to 8 mg/l.

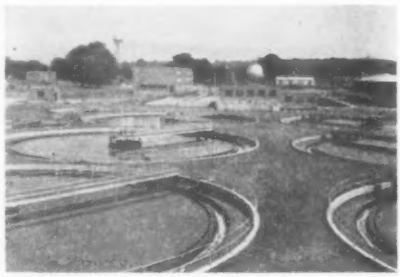

FIGURE 4.—Grand Rapids' activated sludge plant. In the foreground are the final settling tanks.

The following policy was adopted by the City Commission:

> The City of Grand Rapids and its industries have a mutual need for each other. In order to process our sewage to meet required standards, it is necessary to maintain certain maximum concentrations of industrial waste which can be accepted at our Sewage Treatment Plant. It is our opinion that through a review of your manufacturing processes and the establishment of controls to eliminate "dumps" which send increments of high concentrations of toxic materials into our sewers, it may be generally unnecessary for industries to incorporate pre-treatment facilities into their manufacturing processes.

It is intended to give industry a reasonable period to make its own efforts to reduce the amount of deleterious wastes reaching the treatment works. As additional results are reported, progress can be measured. At

present, some waste constituents in Grand Rapids' plant (Figure 4) influent are in excess of the recommended concentrations for the activated sludge process. But the precise effect the limiting concentrations may have on the treatment process and the stream is not completely documented. Moreover, the fate of toxic wastes in the Grand Rapids plant remains to be determined. Extensive investigations along these lines are being planned.

LABORATORY CONTROL FOR THE SMALL TREATMENT PLANT *

By Leroy Forman and Robert Annett

Principal Public Health Engineer, New Jersey Department of Health, Trenton, N. J., and Assistant to the Superintendent, Bergen County Sewer Authority, Little Ferry, N. J.

It is well known that the lack of proper laboratory controls will adversely affect the performance of any treatment plant—large or small. Unfortunately, the small sewage or industrial waste treatment plant with its limited staff usually assigns a very low priority to laboratory control in the operating schedule. A few of the reasons for this situation are:

1. The advantages of laboratory control are not apparent to the operator.
2. There is a lack of training in laboratory-control procedures.
3. There are insufficient manpower and equipment.
4. Often only a minimum of laboratory control is required or accepted by the regulatory agencies concerned.

In the area covered by the first two reasons, it would seem that almost any operator using some of the vast amount of information available should be able to provide a solution. As to the last two reasons, they are beyond the scope of this paper.

The laboratory tests required for any particular plant will, of course, be governed by the type of treatment process. Whether the tests performed will be minimum or very elaborate will depend on conditions and personnel at each plant.

Laboratory Control

Laboratory Manual

"Standard Methods" (1) is the most authoritative, up-to-date manual available on laboratory procedures, but it is written as a reference text for well-trained operators, laboratory technicians, chemists, and engineers. What is needed is a simple practical textbook for the beginner or small plant operator with little previous formal training in the physical sciences. Ideally this book should be well illustrated and contain the following information:

1. an explanation of the principles behind each control test;
2. a step-by-step procedure for each test;
3. instructions on proper laboratory techniques;
4. detailed instructions on the interpretation of the laboratory data and on how these data can be applied to plant operation;
5. complete directions on the care and use of laboratory equipment;
6. a discussion of laboratory records and examples of the proper forms and methods of entry; and

* Presented at the 44th Annual Meeting, New Jersey Sewage and Industrial Wastes Assn.; Atlantic City, N. J.; Mar. 11–13, 1959.

7. a review section on elementary mathematics and formulas.

At the operator's school conducted by the North Jersey Section of the New Jersey Sewage and Industrial Wastes Association it was necessary to use four separate textbooks and booklets (2) (3) (4) (5) to provide the required information on laboratory control.

Training Program

To provide additional training for sewage plant operators, the North Jersey Section of the NJSIWA has been conducting an operator's school for the past four months. From the information gathered by the instructors, it appears that most small sewage and industrial waste treatment plant operators have not had sufficient training in laboratory procedures.

Attempts to teach laboratory procedures by brief demonstrations at the operator's school before a large group (twenty-five) have not proved too successful from either the instructors' or operators' point of view. As a result, a plan to teach laboratory control to small groups of three to five operators is being considered. Under this plan, only one test or procedure at a time will be studied and performed.

As most small plant operators have very little formal training in chemistry, it will be necessary to show how equipment is used, how reagents are prepared, and how solutions are standardized before proceeding with the particular test itself. Finally, the application of test data to plant control will be studied.

This type of intensive laboratory instruction will require a lot of time and effort on the part of all. It will be a heavy burden for any small sectional group and it is hoped that the various agencies and organizations involved in the control and treatment of sewage and industrial wastes will eventually devote more effort to training plant operators. Hardenbergh's (6) excellent article on this subject deserves careful study by everyone concerned with this problem.

Basic Tests for Small Plants

Sampling

A sampling program must be simple for a small plant where the operator is on duty for only 8 hr or less. However, to obtain laboratory results that represent actual operating conditions, a well-planned program of sampling must be worked out.

A convenient method is the "timed-grab" sample (one sample from each stage of the treatment process, timed in a manner to follow a "slug" of sewage through the plant). This method of sampling would suffice as a minimum program for a small treatment plant.

Settleable Solids

The Imhoff cone method is a very simple test, and the results will supply the small plant operator with data on settling tank efficiency and the quantity of sludge to be removed for further treatment. The amount of grease rising to the surface and the sand visible at the bottom of the cone should also be recorded as an aid in anticipating possible future troubles in the digestion tanks.

Relative Stability

This test is very useful for small plants with limited laboratory facilities. The test is normally performed on the plant effluent from biological or secondary treatment processes before chlorination. Results are expressed as the ratio (in per cent) of oxygen available (as dissolved oxygen or nitrates and sulfates) in the sample to the actual BOD or oxygen required for complete oxidation of the sample.

Chlorine Residual

The test for residual chlorine is made to determine whether sufficient chlorine is being added to a plant effluent to disinfect it. The simplest method is a

colorimetric determination employing orthotolidine. It can be performed with a minimum of equipment and takes very little time.

pH

The determination of the pH of digesting sludge or an industrial waste will provide the operator with valuable information for plant control. The test is quite simple to perform with the new, compact, portable pH meter now available. Even the older colorimetric method, with all its limitations, should not be overlooked by the small plant operator working within a limited budget.

Simplified Methods of Laboratory Control

For plant control purposes where a less accurate method will do or time is a factor, the following procedures will usually save considerable time for the operator.

Suspended and Total Solids

The Gooch crucible method for determining suspended solids can be done much easier and quicker by using glass-fiber filter discs instead of the conventional asbestos mat (7) (8).

The Buchner-funnel-and-filter-paper method can be used on mixed liquor as well as sewage samples. As large a sample as possible is used (100 to 1,000 ml) depending on the solids concentration and filterability. The method described in "Standard Methods" (1), is modified to the extent that only filter paper is used in the Buchner funnel, the aluminum dish normally used to support the paper is not required.

In estimating the solids content by the centrifuge method, sludge samples are centrifuged in 15 or 50 ml tubes for a definite period of time (usually 3 to 5 min, using an automatic timing device). The volume in ml of compacted sludge is then recorded. These data are used to determine the concentration of suspended solids in activated sludge or the per cent of dry solids in raw and digested sludges by referring to a calibration curve prepared for the particular type of sludge being checked.

Photometer for Colorimetric Tests

A photometer can be used to simplify and shorten the common tests for ammonia-, nitrite-, and nitrate-nitrogen. The photometer replaces color standards which fade rapidly and are time-consuming to prepare. The photometer value is used with a calibration curve, and nitrogen concentrations are read directly from the graph.

Dissolved Oxygen

This test can be performed faster and with less danger of painful burns from the strong acid and alkali used by substituting Pyrex No. 1340 dropping bottles (60-ml size) equipped with 2.0 ml rubber bulbs for the customary measuring pipette. To prevent the ground glass surfaces from "freezing" together on the bottle containing the alkaline potassium iodide solution, cut a narrow ring of thin rubber tubing and place it on the upper end of the tapered portion of the stopper. This not only keeps the glass surfaces apart, but effectively stoppers the bottle.

Coliform MPN

A newer technique has been developed for estimating coliform densities. It is listed as the membrane filter procedure in "Standard Methods" (8), and a paper on the use of this method was published recently (9). From the data presented, it appears that the membrane filter technique is more precise than the older fermentation tube method, and that, in addition, it has the advantages of saving time and materials.

Laboratory Records

Records of laboratory results are just as important as the operational records of sewage flow, chlorine usage, or equipment maintenance. Elaborate

records for the small plant operator may not be feasible, but the results from a few essential tests conducted regularly should be carefully recorded on a standard record sheet form for monthly and/or yearly periods. This record will make the analysis of the laboratory data much easier.

In the past year alone, several very informative articles have appeared on the importance of maintaining records of laboratory data (10) (11) (12) (13). These articles covered not only laboratory records, but also the importance of coordinating all the records of plant operation.

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SLUDGE UTILIZATION AND DISPOSAL *

By JULIAN R. FLEMING

Director, Division of Sanitary Engineering, Tennessee Department of Public Health, Nashville, Tenn.

The ultimate disposal of sewage sludge is often a vexing problem. Many times the design of the treatment process stops short of this phase of sewage disposal simply because designers as well as operators are not soothsayers. When sludge utilization is relied on as the means of disposal, the public, in one form or another, assumes partnership status in sewage treatment and the results stemming from this alliance are not always predictable.

In spite of these difficulties sludge disposal is accomplished and usually chief credit for it goes to the resourceful operator. In view of this, a knowledge of current practices in sludge utilization and disposal may be helpful to those who are searching for ways to improve sludge handling. It is for this reason that this article on operation practice was prepared.

This paper is organized to present a resume of general methods of sludge

* Presented at the 8th Southern Municipal and Industrial Waste Conf., University of North Carolina; Chapel Hill, N. C.; Apr. 2–3, 1959.

TABLE I.—Solids Content of Sewage Sludge

Kind of Sludge	Solids (%)
Raw sludge:	
Plain sedimentation	2.5–5.0
Trickling filter	5–10
Trickling filter + plain sedimentation	3–6
Activated	0.5–1
Activated, thickened	1–2
Activated + plain sedimentation	4–5
Digested sludge:	
Plain sedimentation	10–15
Trickling filter	10
Activated	2–3
Activated + plain sedimentation	6–8

disposal and a summary of methods used in 28 selected towns in Alabama, Arkansas, Florida, Kentucky, South Carolina, and Tennessee.

Methods of Sludge Disposal

Sewage sludge is that portion of domestic sewage, often mixed with industrial wastes, which settles out in the sedimentation processes. The ranges of the solids content of the various sludges shown in Table I were reported by Fair and Geyer (1).

These values show the solids content in raw sludge may vary from as low as 0.5 per cent to as high as 10 per cent, and from 2 to 15 per cent after digestion. Since sludge is primarily water even after completion of digestion, it may be transported through pipes. Well-digested sludge, with a usual solids content of 5 to 10 per cent, shows a definite thickening and flows less freely than water. At 10-per cent solids, it has the consistency of syrup, and when discharged to a level sludge drying bed it spreads out evenly for about from 50 to 100 ft, but if greater distances are involved, it will tend to be deeper near the discharge point and shallow toward the distant end of the bed. At a solids content of 15 to 20 per cent, the sludge will no longer flow, and at about 25 per cent it can be handled with a spading fork, grader blade, and other tools usually used in handling solids. At 50-per cent solids, it gives the appearance of being almost completely free of moisture, and at 90-per cent solids, it is dust dry.

During the air drying of a 4-per cent sludge to one having, say, 30-per cent solids, the volume is reduced seven- to eight-fold. For an extreme case of wet sludge at 2-per cent solids being reduced by heat to ash, the volume reduces to 1/50 of the original volume.

Sludge is a liability to any sewage treatment plant and the question of ultimate disposal must be decided on the basis of the most economical method, considering fixed charges, operating costs, odor and other nuisance problems, effects of bad weather, amount of space available, etc.

As a means of final disposal, sludge has been:

1. Spread on agricultural land;
2. Spread on golf courses, parks, playgrounds, and lawns;
3. Mixed with other ingredients to form a fertilizer;
4. Incinerated to ash which is then used as fill material;
5. Mixed with refuse in a land fill;
6. Lagooned and eventually used as fill; and
7. Hauled by ships or piped to the ocean.

Use on Land

Digested sludge has a considerable amount of soil-conditioning value, and some value as a fertilizer. Fertilizer value is usually measured in terms of nitrogen (N), phosphoric acid (P_2O_5), and potash (K_2O). The following values from the FSIWA Manual on sludge utilization (2) show its approximate fertilizer value:

Kind of Sludge	Nitrogen Content (%)
Sludge from plain sedimentation	0.8–3.5
Activated sludge	2.0–4.8
Primary + trickling filter sludge	1.0–4.5

Digestion reduces the nitrogen content as much as 40 to 50 per cent. Raw sludge will usually contain from 1 to

3 per cent of P_2O_5 and from 0.1 to 0.3 per cent of K_2O. As noted previously, air-dried or heat-dried sludge has been used widely on golf courses, parks, lawns, and agricultural land.

The principal problems associated with the agricultural use of sludge are occasional odors when the sludge becomes wet, excessive hand labor required to move it from the drying bed, transportation problems, difficulty in proper spreading, necessity for shredding or grinding in many cases, and the possible transmission of disease by contamination of fruits and vegetables which may be eaten uncooked.

Examples of Other Methods of Disposal

Fertilizer Manufacture

Milwaukee, Wis., was one of the first major cities to use the activated

TABLE II.—Sludge Disposal Practice at 28 Cities in the Southeast

City	Plant Type	Est. Pop. Served	Avg Sewage Flow (mgd)	Method of Sludge Disposal	Comments
Alabama:					
Birmingham (Ensley Plant)	Primary	150,000	40	Digested sludge elutriated, vacuum filtered, heat dried, shredded, and sold.	Can be incinerated to ash if desired. Plant in operation approx. 1 yr. Cost data not available.
Ft. Payne	Secondary	6,000	0.6	Digested sludge air dried and given away.	—
Montgomery	Secondary	65,000	5.0	Digested sludge air dried, shredded, and sold at cost.	$4/cu yd unshredded; $5.50/cu yd shredded.
Opelika	Secondary	10,000	1.0	Digested sludge air dried and given away.	—
Prichard	Primary	10,000	0.75	Digested sludge air dried, shredded, and sold.	—
Sylacauga	Secondary	15,000	2	Digested sludge air dried and given away.	—
Arkansas:					
Blytheville	Secondary	17,000	2	Raw sludge vacuum filtered and given away; some used on a landfill.	Solids in filtered sludge, 32%. Filter operates 40–50 hr/mo. Chemical cost approx. $300/mo; power cost approx. $1,000/mo. CaO dosage, 4.7%; $FeCl_3$ dosage, 1.7%.
Jonesboro	Secondary	18,000	1.0	Digested sludge air dried and used on farm land.	Dry weather drying time, 10–14 days/bed.
Florida:					
Coral Gables	Secondary	15,000	2.4	Digested sludge vacuum filtered, heat dried, and sold or given away.	Moisture in dry sludge, 10%. Drying temp., 1200°F. Dried sludge sold to parks dept. for $30/ton. Excess sludge given to U. of Miami. Total cost of handling including depreciation, $50/ton.
Gainesville (U. of Fla.)	Secondary	7,000	0.55	Digested sludge air dried, shredded, and used on grounds.	Sludge depth of 12 in. reduced to 4 in. in 17 days, with 25% solids; 20% solids in 11 days. Univ. depts. pay for removal and hauling.
Orlando	Secondary	75,000	7.0	Most digested sludge air dried and stock piled. Liquid sludge sold to fruit growers.	Dried sludge removed by convict labor. Liquid sludge sells for $1/1,000 gal. Operation controlled by state health dept.
Pensacola	Primary	50,000	4.2	Digested sludge vacuum filtered, air dried, shredded, and used on farm land.	Solids in filtered sludge, 35%. Cake spread in remote area for air drying. City has 2 treatment plants.
St. Petersburg	Primary	—	—	Digested sludge air dried and used on parks.	City has 4 treatment plants; 3 plants use sand beds; 4th plant uses slag beds. Est. cost of removing sludge from beds, stock piling, and application is $2.50/cu yd.
Tallahassee	Secondary	45,000	3.7	Liquid digested sludge is hauled to a sanitary landfill for burial.	Est. cost of disposal is $8.70/1,000 gal.
Tampa	Primary	185,000	20	Digested sludge air dried and used on parks.	Twenty-eight 50- × 125-ft sand beds used; total area is 175,000 sq ft.
Kentucky:					
Louisville	Primary	510,000*	100*	Digested sludge vacuum filtered and hauled to disposal site by special trucks.	Plant serves Louisville and Jefferson Co. Metropolitan Sewer Dist.

TABLE II.—*Continued*

City	Plant Type	Est. Pop. Served	Avg Sewage Flow (mgd)	Method of Sludge Disposal	Comments
South Carolina:					
Greenwood	Secondary	7,000	—	Digested sludge air dried and sold or given away.	In winter, 20–140 mg/l of alum fed to wet sludge. Portion of sludge sold to farmers. Normally, sludge removed by hand labor and stock piled.
Spartanburg	Primary	—	3*	Digested sludge air dried and sold.	Lawson's Fork Plant. Sludge removed by hand labor, stockpiled on conc. apron, and sold for $1/cu yd.
Spartanburg	Secondary	—	5.5*	Digested sludge pumped directly to agricultural land.	Fairforest Creek Plant. Aluminum pipe used to convey liquid sludge. Method considered most satisfactory.
Tennessee:					
Bolivar	Secondary	3,000	0.4	Digested sludge air dried and used on plant grounds or given away.	Drying time varies from 6 wk to 3 mo.
Bristol	Secondary	40,000	6.0*	Digested sludge air dried and used on city grounds. Some liquid sludge hauled to farms.	Summer drying time, 30–90 days; winter, up to 6 mo. Odor problems present, may be due to non-digestibles from industry.
Elizabethton	Primary	12,000	1.3	Raw sludge vacuum filtered and hauled away by farmers or City.	Filter cake, 25% solids. Filtration usually 3 days a week. Estimated annual cost of sludge operation is $6,000 against $11,000 for digesters and drying beds. No odor problems.
Johnson City	Primary	30,000	—	Digested sludge air dried and sold or given away.	Dried sludge, 52% solids. Summer drying time, 15–20 days; winter, 2–3½ mo.
Kingsport	Primary	24,000	4	Digested sludge air dried, shredded, and used on plant grounds or given away. Some liquid sludge piped to plant grounds.	Dried sludge, 45% solids. Summer drying time, 30 days; winter, 2–3 mo.
Knoxville	Primary	125,000	20–36	Digested sludge elutriated, vacuum filtered, and hauled to City airport. Some sludge sold and some used on parks.	Filter cake, 32% solids. Heat drying and sacking are under investigation.
Lebanon	Secondary	10,000	—	Digested sludge air dried and given away.	Min drying time, 7–12 days; max, 1½–2 mo. Beds kept scrupulously clean. Effective size of sand, 2.0 mm.
Maryville	Secondary	8,500	—	Digested sludge air dried.	Dried sludge, 25–35% solids. Raw sludge concentrated prior to digestion.
Murfreesboro	Secondary	30,000†	1–1.5	Digested sludge hauled to farm land. Small portion is air dried.	1,000-gal portable tank can be filled in 10 min. Sludge discharge over flared chute to produce 6-ft wide sheet of sludge. Truck speed adjusted to control application.
Union City	Secondary	8,300‡	1.3	Raw sludge vacuum filtered and used on farm land.	Operating cost per ton of dry solids: 1956, $23.00; 1957, $13.80; and 1958, $9.82. Plant overloaded with meat packing wastes.

* Design value.
† Includes industrial population equivalent of 15,000.
‡ Population equivalent equals about 31,000.

sludge process. This plant was and is unique in that it does not use primary sedimentation, but instead uses revolving drum screens to remove all coarse and medium solids. The drum screens are followed by the activated sludge process, with final settling. The sludge goes to a rotary kiln dryer and at the completion of the drying process, it is ground and sacked. Its nitrogen content is rather high, and it is sold under the trade name of "Milorganite" in competition with commercial fertilizers over a large portion of the United States. Though probably not economically profitable when all cost items are considered, this method of sludge disposal has solved that problem and has done much toward meeting operating expenses for the treatment plant.

Ocean Disposal

Recently the city of Los Angeles, Calif., was faced with the necessity

of increasing sludge handling and disposal facilities to accommodate the rapidly growing load on the treatment plant. The final choice of handling the sludge was to build a 22-in. diameter pipeline (3), 7 miles long, to take the sludge to the Pacific Ocean at a point 312 ft deep. This line has a capacity of 5.5 mgd. With an estimated sludge flow rate of 2.45 mgd, the remainder of the pipeline capacity is utilized by mixing the liquid effluent of the plant with the digested sludge in proper proportions. Velocity in the pipeline is approximately 4 fps.

The city of New York has a complex system of sewage treatment plants scattered around Manhattan and the other boroughs. For the past 22 years digested sludge has been hauled to the deep water of the Atlantic Ocean for final disposal. In 1953 the sludge fleet consisted of three vessels. At that time the total cost of digestion and the ultimate disposal of sludge was $9.80 per ton of dry solids. More than 75 per cent of this cost was direct operating cost. New York also has pumped a rather small amount of sludge through a short pipeline to be mixed with other ingredients in the manufacture of a synthetic top soil for use in city parks.

Sludge Disposal Practices in the Southeast

Alabama

Sludge disposal practices at six treatment plants are summarized in Table II. With the exception of the Ensley plant in Birmingham, sludge is dried on open beds. Nearly all of the newer plants with capacities above 0.5 mgd are equipped with sludge shredders. Shredding seems to make the sludge easier to use, less odorous, and, therefore, easier to market or give away.

Over the state as a whole, the sale of air-dried sludge is increasing, but there are few localities where the demand is great enough to defray the expense of removing the material from the drying beds.

The State Health Department advises against the use of air-dried sludge on edible crops and suggests that its application be limited to beef cattle pastures, lawns, shrubbery, flower beds, or inedible row crops.

Arkansas, Florida, Kentucky, and South Carolina

Sludge disposal practices at 12 cities in Arkansas, Florida, Kentucky, and South Carolina are summarized in Table II.

Tennessee

Sludge disposal practices in 10 Tennessee cities are summarized in Table II.

In Kingsport, a small amount of liquid sludge has been used on the plant grounds. Labor savings more than paid for the cost of the 180 ft of pipe used. More extensive use of this method of disposal is planned.

At Murfreesboro, because of the ease of handling, liquid sludge is in steady demand. The demand for dried sludge is minor because of the greater labor requirements associated with its use.

Acknowledgment

To the superintendents and operators of the treatment plants listed in Table II and to the various state health department officials go many thanks for their co-operation in supplying so much of the reported information on sludge disposal practices.

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TIPS AND QUIPS

State-Industry Cooperation *

The Oregon State Sanitary Authority, the Washington Pollution Control Commission, and five pulp and paper mills have begun an intensive, cooperative study of water quality conditions on the lower Columbia River. The purpose is to establish a baseline on water quality which will (a) measure the results of water pollution abatement facilities, (b) measure the long-range changes in quality caused by industrial, urban, agricultural, recreation, land, and water resources developments, and (c) show causes of pollutional problems. Forty-six water samples will be collected twice monthly at 11 stations on the 80-mile stretch of the river from Bonneville Dam to Puget Sound.

Cooperating mills are Columbia River Paper Mills at Vancouver, Wash., the Camas, Wash., and St. Helens, Ore., divisions of Crown Zellerbach Corporation, and Longview Fiber Company and Weyerhaeuser Timber Company at Longview, Wash.

Pennsylvania OK's Lagoons

In a recent action of the Pennsylvania Sanitary Water Board the lagoon method of sewage treatment has been given approval for use in areas where soil conditions, terrain, and the receiving stream are considered suitable.

The Board previously had limited the use of stabilization ponds to a single location near Pittsburgh to determine whether the method would perform satisfactorily. This experimental installation was placed in service near the end of 1958.

Governor David Lawrence called the Board's action ". . . a major step forward in community health planning. . . ."

Oil on Untroubled Waters Causes Trouble

Several months ago we read in the *Quarterly Bulletin* of the Michigan Water Resources Commission that more than ⅓ mil gal of heavy fuel oil was lost to the waters of Lake Michigan when an oil barge sank near Gary, Ind.

In the latest *Bulletin* we read that a survey in June along the Michigan shore of Lake Michigan showed the oil accumulation is either a critical clean-up problem or a serious nuisance along approximately 115 miles of shoreline. We also noted that "Corrective measures range from bulldozing heavier concentrations to hand-picking the scattered blobs—all laborious and costly. . . ."

Foam Corral *

In Figure 1 you can see how foam from the Hammermill Paper Company's pulping and bleaching plant used to spread across the waters of Lake Erie. Control of the effluent proved complicated because of the large volume as well as the surface active agents it contained.

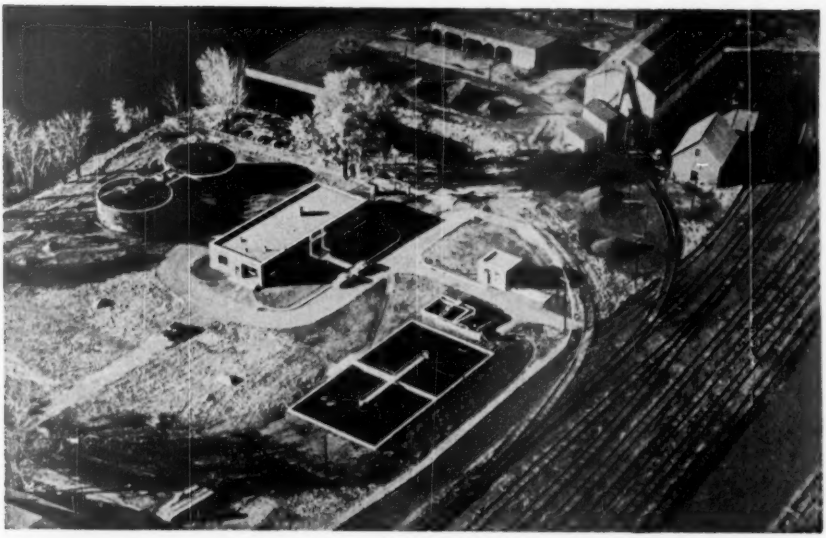
Success came (Figure 2) when the Company installed a 300-ft floating rubber boom to confine the thick, tough foam to a small area, where it tends to break up. Flexible sections permit the boom to withstand wave action.

* From *Northwest Pulp & Paper News* (June-July, 1959).

* From *Clean Waters* (Mar. 1959).

FIGURE 1.—Foam formerly spread for miles across Lake Erie's surface.

FIGURE 2.—Now foam stays corralled in a small area and breaks up under its own weight.



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S-13

Proceedings of Member Associations

CALIFORNIA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 31st Annual Meeting of the California Sewage and Industrial Wastes Association was held at the Lafayette Hotel, Long Beach, Calif., Apr. 29–May 2, 1959. Hosts for the meeting were the Los Angeles Sewer Maintenance Section and the Los Angeles Operators Section. Registration totaled 453, including 103 ladies.

General arrangements were directed by Sydney Preen, and Paul Hennessy was in charge of the program.

The technical program offered full coverage of the wastewater field and among the subjects discussed were: curved sewers, urban growth patterns, sanitation in space, relations with management and the public, the California water pollution control monitoring program, plant maintenance and lubrication, safety, oil field brine wastes, underground disposal of radioactive wastes, Zimmerman process, massive chlorination, pumping plant design, and the role of nitrates in sewerage systems.

A field trip to Los Angeles' Hyperion treatment works was the highlight of the last day of the meeting.

At the award luncheon, Federation President W. D. Hatfield presented the Bedell Award for outstanding service to the Association to Raymond Ribal, Consulting Engineer, Fullerton, Calif., and the Hatfield Award recognizing excellence of treatment works

(*Continued on page 488a*)

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operation went to Melvin Klemmick, Chief Operator, Sonoma Valley County Sanitary District, Sonoma, Calif.

The following officers were elected for the year 1959–60:

President: P. H. McGauhey, Berkeley.
First Vice-President: Dennis O'Leary, San Diego.
Second Vice-President: Elmer Ross, Oakland.
Director: Robert D. Bargman, Los Angeles.
Secretary-Treasurer: Alfred D. Leipzig, Venice.

ALFRED D. LEIPZIG
Secretary-Treasurer

MONTANA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The joint meeting of the Montana Section of the American Water Works Association and the Montana Sewage and Industrial Wastes Association was held in Glendive, Mont., Apr. 9–11, 1959. The total registration was 115, including 27 ladies.

The technical portion of the program started with a presentation by C. W. Brinck, Director, Division of Environmental Sanitation, Montana State Board of Health, who discussed "Stream Pollution Progress in Montana."

A panel discussion was held on sewage disposal and Verne Reed, City Engineer, Livingston, Mont., served as moderator. The first topic was "Activated Sludge Treatment," presented by A. P. Nichols, Operator, Sewage Treatment Plant, Montana State Tuberculosis Sanitarium, Galen, Mont.; "Primary Sewage Treatment" was discussed by John Voelker; and "Sewage Lagoon Operation" was discussed by D. F. Cuskelley, City Engineer, Dickinson, N. Dak. A review of the other

(*Continued on page 490a*)

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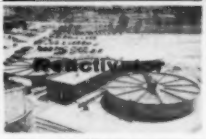
MAXIMUM SOLIDS REMOVAL	Reactivator*	 Reactivator*	Reactivator*
MINIMUM SPACE REQUIRED	Reactivator*	Clariflotor*	Clariflotor*
LEAST COSTS	Rota-Rake*	Rota-Rake*	Clariflotor*
RECOVERY	Ion Exchanger	Reactivator*	Clariflotor*

*Reactivator—high-rate solids-contact clarifier and softener *Clariflotor—flotation unit *Rota-Rake—horizontal flow gravity clarifier

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common types of sewage treatment was given by William Wenzel, Consulting Engineer, Great Falls, Mont.

Another timely topic discussed was "Should Water and Sewage Plant Operators be Licensed?" This was a renewal of an old topic and Fred Palmer, Consulting Engineer, Forsyth, Mont., former chairman of the committee on licensing, told of past action on this topic.

A buffet supper on Thursday night and a dinner-dance on Friday night rounded out the social activities of the meeting.

The annual business meeting was held on the morning of Apr. 11. Reports of all standing committees were presented and the business meeting was concluded with the election of the following officers for 1959–60:

Chairman: E. R. Waldo, Billings.
Vice-Chairman: Paul Williams, Helena.
Secretary-Treasurer: A. W. Clarkson, Helena.

A. W. Clarkson
Secretary-Treasurer

MICHIGAN SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The Michigan Sewage and Industrial Wastes Association held its 34th Annual Meeting at the Wenonah Hotel, Bay City, Mich., May 11–13, 1959. A total of 271 members and their guests was registered. In addition 61 women attended the social events. Again this year all previous attendance records were broken.

The technical conference was opened on Monday afternoon with a symposium on sludge digestion. Basic theory was discussed by C. Preston

(*Continued on page 492a*)

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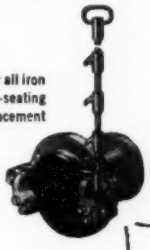

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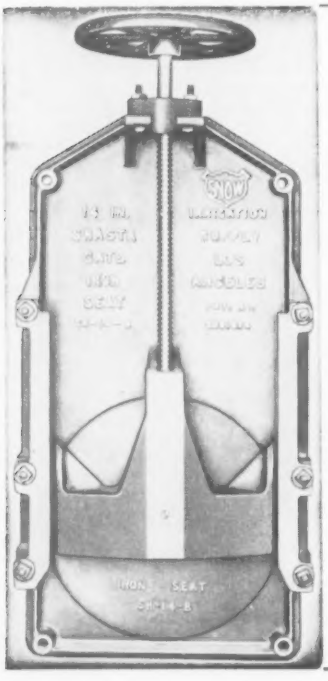
Witcher, Superintendent of Sewage Treatment, Ann Arbor; "design" by George E. Hubbell, Consulting Engineer of Birmingham; "operation problems" by R. A. Greene, Superintendent, Sewage Treatment, Jackson; and "control procedures" by Huntley DeLano, Superintendent of Sewage Treatment, Grand Rapids.

Of equal interest was the symposium on trickling filters presented on Tuesday morning. Karl L. Schulze, Associate Professor, Michigan State University, discussed basic theory; Cletus Courchaine, Sanitary Engineer, Michigan Department of Health, discussed performance of 25 trickling filter plants in Michigan; Nelson Willie, Superintendent of Sewage Treatment, Cass City, discussed summer and winter operation; Russell Smalla, Superintendent, Sewage Treatment, Lake Odessa, discussed treatment of canning wastes; and Floyd Kimball, Superintendent of Sewage Treatment, Lapeer, discussed treatment of wastes from a pickle plant.

Concurrently on Tuesday, a symposium on industrial wastes covered the following subjects: "Proper Methods of Sampling," by Gerald D. Wingeart, Sanitary Engineer, Wayne County Metropolitan Sewerage System; "Conditioning of Buick's Industrial Waste Sludge," was presented by Robert J. Brink, Research Engineer, Buick Motor Division, General Motors Corporation, and "Statistical Basis for Interpretation of Data," was discussed by John Gannon, Associate Professor, School of Public Health, University of Michigan.

On Tuesday afternoon, "gadgets," which were on display throughout the entire conference, were explained by each of 12 persons who had entered

(*Continued on page 494a*)



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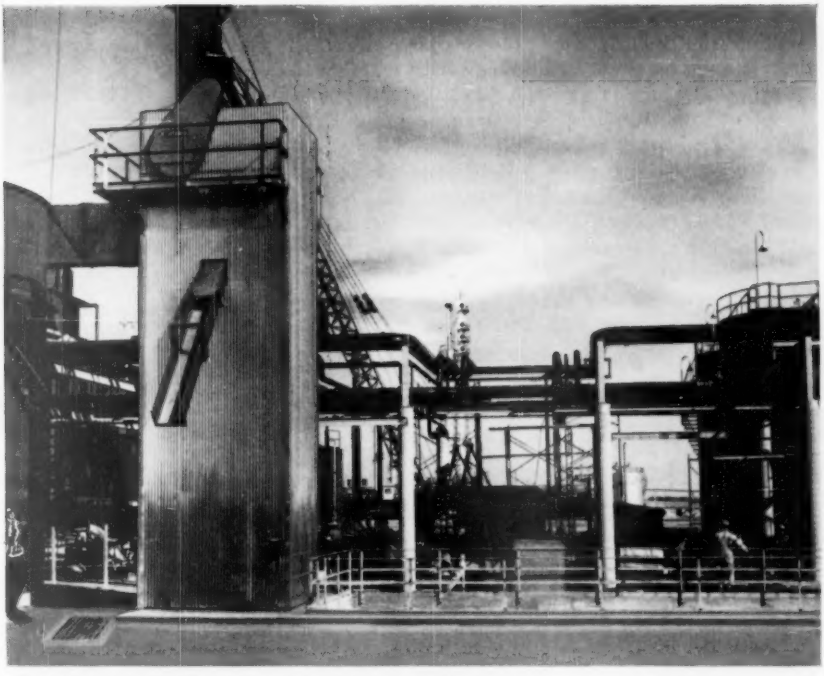

Jeffrey system recovers coke fines at Skelly refinery

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The ½" x 0 coke fines, weighing 50 pounds per cubic foot, are washed up in water, which then pass through a settling tank. As the fines drop to the bottom of the tank, a continuous V Bucket Collector removes the fines, conveys and elevates them at rates up to 6½ tons per hour.

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Jeffrey V Bucket Collector recovers coke fines from settling tank at Skelly Oil Company refinery, El Dorado, Kansas. The system also permits reuse of the water.

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some piece of equipment, adaptation, or innovation, or a facsimile thereof, in competition for the gadgets award. Huntley DeLano, Chairman of the Gadget Committee, was in charge of this session. Other papers completing the afternoon session were: "Design of the New Warren Sewage Treatment Plant," by Clare Johnson, Johnson and Anderson, Consulting Engineers; "Split Chlorination Effectively Reduces Coliforms at Bay City," by John Sherbeck, Superintendent of Sewage Treatment; and "Heating Digesters with Steam Injection," by Merle Davis, Superintendent of Sewage Treatment, Hillsdale.

The conference was concluded with the technical session on Wednesday morning which began with a paper presented by Ralph W. Purdy, Sanitary Engineer, Water Resources Commission, on "How to Determine Self-Purification Capacity of a Stream."

FSIWA Past-President K. S. Watson presented the Hatfield Award to Stanley J. Mogelnicki, Research and Development Engineer, Dow Chemical Co., Midland, and the Bedell Award went to Donald M. Pierce, Chief, Sewerage and Sewage Treatment Section, Division of Engineering, Michigan Department of Health, Lansing.

At the annual business meeting the following officers were elected for the year 1959–60:

President: Frank Kallin, Dearborn.

First Vice-President: John Sherbeck, Bay City.

Second Vice-President: John Hennessey, Pontiac.

Secretary-Treasurer: Donald M. Pierce, Lansing.

DONALD M. PIERCE
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(*Continued on page 496a*)

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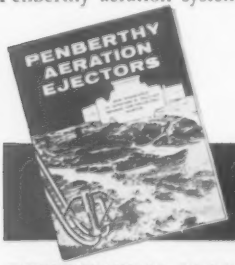

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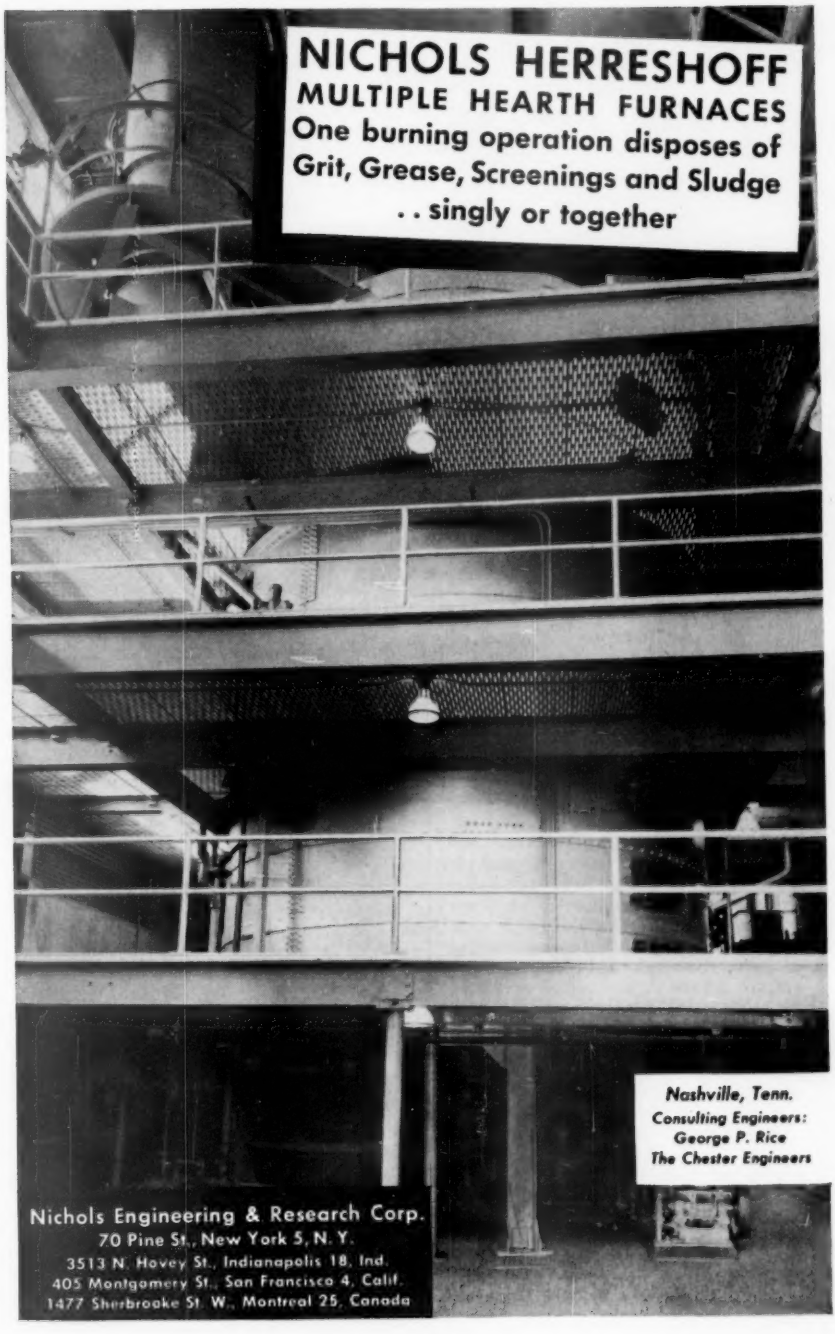
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ISRAEL SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The Sanitary Engineering Laboratories at the Technion, in cooperation with the Israel Sewage and Industrial Wastes Association, held a one-day symposium on June 16, 1959, on "Industrial Waste Problems," at Technion City, the new campus of the Israel Institute of Technology in Haifa.

There were 112 registered participants, besides 25 students who attended the sessions. Representatives of the Ministries of Health and Agriculture, of equipment manufacturers, and of many industries were among those present.

The following papers were read:

"The Need for Treatment of Industrial Wastes," by Yehuda Peter, Associate Professor of Sanitary Engineering at the Technion.

"Principles of Industrial Waste Treatment," by Alberto M. Wachs, World Health Organization Adviser and in charge of the Sanitary Engineering Laboratories.

"Legal Aspects of Industrial Waste Disposal," by Hillel Shuval, Acting Director of Public Health Services, Ministry of Health.

"Industrial Waste Problems in the Dan Region," by Moshe Markuze, Chief Sanitary Engineer, Federation of Dan Region Municipalities.

"Special Problems in Industrial Waste Disposal," by Gerald Parker, Lecturer, Sanitary Engineering Laboratories, Technion.

All of the registrants visited the Sanitary Engineering Laboratories where various methods of treating industrial wastes were demonstrated.

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Application shall be made only in writing, in duplicate, and should state experience, education, age, present salary, expected salary and any recommendations, and should be addressed to: Mr. R. J. Brennan, Chairman, Bradford Sanitary Authority, 101 Main Street, Bradford, Pennsylvania.

All replies will be strictly confidential.

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Equipment and Supply Lines

First Aid Station—A new first aid cabinet small enough to mount near hazardous areas, yet large enough to hold necessary first aid items, is shown in Figure 1. The doors will not open as a result of vibration. The 11-cu ft cabinet is finished in white, baked-on enamel.—General Scientific Equipment Co., 7516 Limekiln Pike, Philadelphia 50, Pa.

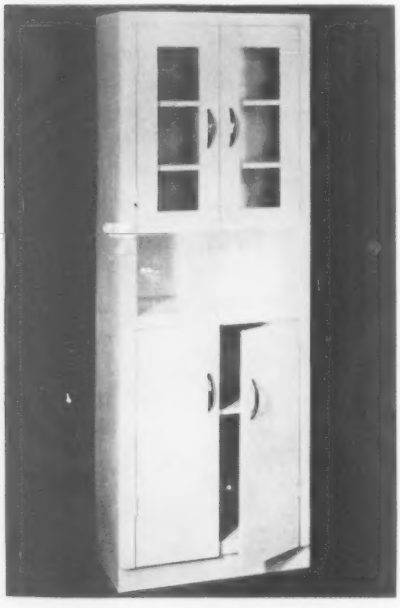

FIGURE 1.—First aid cabinet (66 in. high, 24 in. wide, and 12 in. deep) with rounded-corner construction, one-piece doors, and platform base.

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FIGURE 2.—Laboratory pump.

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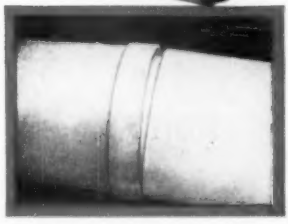

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